THE DEGREE OF SOIL WATER SATURATION IN THE NARROW-LEAVED ASH (*Fraxinus angustifolia* Vahl.) FLOODPLAIN FOREST

NIKOLA PERNAR, IGOR ANIĆ, ANAMARIJA JAZBEC, DARKO BAKŠIĆ

Faculty of Forestry, Institute of Silviculture, P. O. Box 422, HR-10000 Zagreb, Croatia; e-mail: pernar@hi.htnet.hr

Abstract

Pernar N., Anić I., Jazbec A., Bakšić D.: The degree of soil water saturation in the narrow-leaved ash (*Fraxinus angustifolia* V a h l.) floodplain forest. Ekológia (Bratislava), Vol. 26, No. 3, p. 258–272, 2007.

Research is aimed at analysing the dynamics of the soil water saturation degree (FDR method) during three characteristic developmental phases of ash stands. The studied stands are located in the lowland forest in Upper Posavina (a part of the Sava river valley) in Croatia. The experiment was established in natural stands of a community of narrow-leaved ash with autumn snowflake (*Leucoio-Fraxinetum angustifoliae* G l a v. 1959), which is distributed in the area dominated by the community of pedunculate oak and great greenweed (*Genisto elatae-Quercetum roboris* R a u š 1969). Three locations in a micro-depression of a flooded plain were chosen: 1) the lowest micro-relief position – the bottom of a bogged site – initial development phase; 2) the central micro-relief position – optimal development phase; 3) the marginal bogged area towards a fresh micro-depression – terminal development phase. The degree of water content in the soil is regarded a very practical indicator of ash stand conditions, in which the soil in the lower part of the rhizosphere (in the initial phase it is within a depth of 1 m) is completely saturated with water over most of the year or the whole year. Anaerobiosis, or reduction conditions in the soil correspond to the soil saturation degree. In terms of the degree of soil water saturation, the terminal phase of ash forest is the most distinct, while in terms of total water quantity in the profile and its dynamics, the initial phase takes up the first place. Based on research we can concluse that developmental phases differ from one another in the dynamics of soil water saturation at almost all depths. At the beginning of a drier vegetation period there was no difference between the initial and the optimal phase in the bare regeneration area, and between the terminal and the optimal phase in the old stand. Similarity between these pairs was evident throughout the vegetation period. In the year with a more humid vegetation period, this differentiation regularity was hardly evident in terms of saturation degree dynamics. In conditions of a drier vegetation period (2000), the most favourable distribution of water in the soil occurred in the terminal phase.

Key words: soil water saturation degree, FDR method, narrow-leaved ash, stands of narrow-leaved ash

Introduction

A floodplain forest grows in specific hydrological conditions. Its biological particularity, combined with its ecological and economic function, is a trigger mechanism for the study of patterns of its internal processes. Water is the most important factor in these processes.

Soil water is usually a very dynamic component. In case of floodplain forests, this dynamics is less distinct because soil is completely saturated with water for long periods. This feature is directly reflected on the reduced soil air dynamics.

The annual and seasonal water component dynamics in the soil of a floodplain forest are particularly interesting in a highly indented microrelief. Apart from the microrelief, this variability also depends on soil properties and on the characteristics of the forest plant cover: tree species, age and distribution in space (Hewlett, 1982; Likens et al., 1995; Mallants et al., 1996; Bruckner et al., 1999; Schume et al., 2003). Soil moisture and soil clay content have a vital effect on the organic carbon content and microbiological mass, as well as on the degree of nitrification (Eaton, 2000; Härdtle et al., 2003).

Wessolek (2001) deals with the problem of determining (measuring) the water component in a forest ecosystem, while Strohback and Degenhardt (1999) and Hörmann and Meesenburg (2000) gained very valuable insights into terrestrial conditions. This problem is also manifested in modelling ecosystem water balance (Evans et al., 1999). In the last two decades the development of a water balance model in a forest ecosystem has received strong impetus by the application of recent methods of monitoring water in the soil (Bell et al., 1987; Dean et al., 1987; Seyfried and Murdock, 2001). These methods are based mainly on measuring dielectric soil coefficient (Hilhorst, 1997), by using TDR (Time Domain Reflectometry) or FDR (Frequency Domain Reflectometry) systems.

The forest of narrow-leaved ash (*Fraxinus angustifolia*) has a prominent place within the issue of floodplain forest hydrology. In relation to water, narrow-leaved ash is a hygrophytic species. It grows on a range of sites starting from bogged sites, where it forms a boggy forest boundary towards a swamp, to fresh flatland microelevations. Since the floristic-vegetational and forest-economic aspect of an ash forest in different relief positions changes fundamentally, there is a question of the existence of possible differences and of their nature in the soil of the sites with such microrelief.

Our research focuses on the dynamics of the degree of soil water saturation in ash stands of a floodplain lowland forest in the growing season.

Research is aimed at analysing the dynamics of the soil water saturation degree during three characteristic evolution phases of ash stands. Data for each evolution phase are dealt with separately and differences among them are analysed.

Study site and methods

Site and stand

The studied stands are located in the lowland forest of Josip Kozarac in Upper Posavina (a part of the Sava river valley) in Croatia (Fig. 1). This forest extends between 45°20' N and 45°26' N and 16°45' E and 16°53' E , at an altitude between 93.5 and 104.1 m. The average (26-year period) annual precipitation quantity is 860 mm, and air temperature is 9.9° C. The average precipitation quantity in the growing season is 454 mm, and air temperature is 16.1° C. The dominant soil type is Gleysol, with Planosol being represented to a somewhat lesser degree.

Fig. 1. Study site.

The experiment was established in natural stands of a community of narrow-leaved ash with autumn snowflake (*Leucoio-Fraxinetum angustifoliae* G l a v. 1959), which is distributed in the area dominated by the community of pedunculate oak and great greenweed (*Genisto elatae-Quercetum roboris* R a u š 1969). Three locations in a micro-depression of a flooded plain were chosen:

1. the lowest microrelief position – the bottom of a bogged site
2. the central microrelief position
3. the marginal bogged area towards a fresh microdepression.

Sites 1 and 2 are situated at a distance of approximately 300 m from one another and belong to the same microdepression, with an altitudinal difference less than 1 m. Site 3 is slightly further away from sites 1 and 2 (800 m) and represents the marginal area of a moist central microrelief position towards the higher part of microdepression. When floodwaters recede in late spring, sites 1 and 2 (especially site 1) remain saturated with surface stagnant water for some time, while water in site 3 recedes earlier.

From the aspect of evolution and syndynamics of the forest of narrow-leaved ash, site 1 represents an initial (moist) phase of ash forest, site 2 an optimal (humid) phase, and site 3 a terminal (fresh) phase. The experiment in the initial ash phase was established in a 19-year-old stand of narrow-leaved ash over a 30x30 m square. The experiment in the optimal ash phase was established in two variants. The first variant was set in a bare regeneration area after old stands of narrow-leaved ash had been cut down in an area of 35x200 m. The second variant was set in an old stand immediately next to the first one over an equal-sized area. The experiment in the terminal phase was set in a middle-aged, 57-year-old stand of narrow-leaved ash with pedunculate oak and lowland elm in a 50x50 m square.

Phytocoenologically, the sites differ from one another. The difference linked to the lower participation of hydrophytic species in the terminal phase in relation to the initial and optimal one is particularly distinct. According to the eco-indicator site moisture scale (Ellenberg, 1979), the character of site moisture clearly decreases from the initial towards the terminal phase. The most prominent trend in the change of this indicator is found between the variants of the optimal phase. The variant over a regeneration area (bare soil) proved to be a much more moist site.

With respect to pedophysiographic features (Table 1), it is clear that the terminal phase of ash forest differs considerably from the initial and the optimal phase. This refers particularly to particle size distribution, pH values and air capacity of the soil. The soil in the sites of the initial and the optimal phase has more prominent endomorphological diversity (more horizons). It is also texturally heavier, its pH values in the surface horizons are lower and it has lower air capacity. Although the soil type in all three sites is Gleysol, it should be pointed out that in the initial and the optimal phase the soil is more clayey (refers to vertic character), while in the terminal phase the soil is loamy to loamy-clayey, of a loess-like character.

From a commercial point of view, these are natural even-aged stands of varying ages in which narrow-leaved ash is the dominant tree species.

T a b l e 1. Physiographic soil characteristics in the studied sites.

Phase of ash forest	Soil	Hori-zon	Depth	Particle size distribution				Bulk density	Porosity	Water capacity	Air capacity	pH[a]	C org.
				Coarse sand	Fine sand	Silt	Clay						
			(cm)	(%)				g cm^{-3}	(vol %)				g kg^{-1}
Initial phase	Gleysol	Ag	0–7	0	17.5	40.6	41.9	0.83	64.4	58.7	5.7	5.69	89.4
		Brl	8–25	1	9.8	32.1	57.1	1.15	52.9	52.0	0.9	6.20	21.0
		Brl	26–55	0	9.9	27.6	62.5	1.19	52.4	51.5	0.9	6.75	36.6
		Brl	56–75	1	7.4	25.7	65.9	1.22	51.2	48.4	2.8	7.13	9.6
		Cr	76–100	1	6.4	20.6	72.0	1.37	45.2	43.2	2.0	7.23	6.9
		Cr	101–120	0.9	12.4	14.3	72.4	1.24	50.4	47.5	2.9	7.59	3.9
Optimal phase	Gleysol	Ag	0–14	0	13.1	46.3	40.6	0.99	56.4	50.1	6.3	5.67	42,0
		Br	15–40	0	25.1	21.9	53.0	1.19	51.3	49.7	1.6	6.56	19.5
		Brl	41–83	1.7	21.3	18.6	58.4	1.34	45.1	41.4	3.7	7.42	9.3
		Cr	84–120	0	10.4	32.4	57.2	1.47	39.8	38.3	1.5	7.47	11.4
Terminal phase	Gleysol	A	0–11	1.3	28.5	47.2	23.0	1.00	58.0	49.0	9.0	6.88	66.6
		Bl	12–50	1.9	20.6	42.5	35.0	1.39	45.8	41.2	4.6	7.49	62.1
		Cl	51–100	1	36.2	28.5	34.3	1.45	44.9	35.6	9.3	7.80	6.0

a – pH measured in water suspension

Notes: A – surface mineral horizon, Ag – surface mineral horizon with stagnic condition, Brl – gleyic horizon with capillary fringe mootling and reduction properties, Bl_r – gleyic horizon with capillary fringe mootling, Br – gleyic horizon with dominant reduction properties, Cr – horizon with strong reduction, Cl – horizon with capillary fringe mootling

Data sampling and analysis

To collect general pedophysiographic data, the soil was sampled from the soil profile (pit) in the phase of each site. Soil data are shown in Table 1. Particle size distribution was determined by sieving and pipetting methods, bulk density with Kopecky cylinder, the pH was determined electrometrically, and the quantity of organic carbon was determined with potassium dichromate oxidation. To monitor soil water content, the FDR (capacitance) technology was used. The system of the company AquaPro Sensors (aquapro-sensors.com) was applied, including a moisture meter, a moisture sensor probe and polycarbonate sensing tubes with caps. There were 10 tubes vertically installed in the soil in such a way that moisture meter readings between 0 and 90 cm depth could theoretically be monitored.

The tubes were distributed in the following manner:

– two in the initial phase
– six in the optimal phase
– three in the old stand variant
– three in the bare area variant
– two in the terminal phase

Soil moisture (in fact, soil capacitance) was measured at every 10 cm between 5 and 85 cm. In such a case, the value at 5 cm depth represents a layer from 0 to 10 cm, and the value at 15 cm depth represents a layer from 10 to 20 cm, etc.

In 2000, after the tubes were installed, measurements were done every 6–8 days between May 3rd and November 2nd, and in 2001 between May 31st and September 27th, with the goal of encompassing the growing season in both years. This was not fully possible for the year 2001 due to spring and autumn flooding. The values obtained by readings on the FDR moisture meter were calibrated.

It should be born in mind that the values of readings on the TDR and FDR moisture meters are directly affected by soil texture; consequently, calibration is necessary (Rawls et al., 1991; Brandelik, Hübner, 1996; Hilhorst, 1997; Ponizovsky et al., 1999; Veldkamp, O'Brien, 2000). The FDR data were calibrated on the basis of gravimetrically measured moisture in the soil samples and on the basis of readings on the moisture meter. The samples were taken on several occasions from varying depths at points near those where the tubes were installed. Fifty samples were taken in this way every year. The values of readings from the moisture meter were linearly regressed in accordance with the moisture of these soil samples. Mass percentages of soil moisture were thus obtained, which were then converted into volume percentages by using volume soil density. These values were correlated in terms of soil porosity at a given depth measured on profile samples. They are expressed in percentages, that is, as a degree of soil water saturation.

Degree of soil water saturation = soil moisture/porosity x 100

Based on the data of saturation degree, the water content (water column) to a depth of 90 cm for each measurement was expressed for each tube.

To test the differences in the degree of soil water saturation among developmental phases of ash forests (initial, optimal – over a bare area and in the old stand, terminal phase), variance analysis (ANOVA) was used with repeated measurements, using the effects of phase, time or depth and their interactions. Model 1 (Table 2) was used to test the differences in the degree of soil saturation among the phases by individual depths over a year (for each year separately). Model 2 (Table 2) was used to test the difference in the degree of soil saturation among the phases across the entire depth for each date of measurement. When the phase effect proved to be statistically significant, the Tukey multi-comparison post hoc test (Sokal, Rohlf, 1994) was used to test the phases that differed from one another. For all type I analyses, an error of 5% was considered statistically significant (bolded in tables).

All statistical analyses and graphical presentations were done with the SAS 8.12 and STATISTICA 6.0 statistical software.

Meteorological data were taken from the meteorological station Opeke, several hundred metres away from the studied sites.

T a b l e 2. Models of testing differences in the degree of soil water saturation in developmental phases of ash forest.

	Model 1			Model 2			
	Source of variation	df (2000)	df (2001)	Source of variation	df (2000, 2001)	MS	F
Between moisture meters	Natural site	3	3	Natural site	3	(1)	(1/2)
	FDR moisture meter inside natural site	6	6	FDR moisture meter inside natural site	6	(2)	
Within moisture meters	Time	26	16	Soil depth	8	(3)	(3/5)
	Time * natural site	78	48	Natural site * soil depth	24	(4)	(4/5)
	Time * FDR moisture meter inside natural site	156	96	Soil depth * FDR moisture meter inside natural site	48	(5)	

Notes: df – degrees of freedom, MS – mean square, F – F value

Results

Fig. 2 shows the dynamics of soil water saturation degree in different developmental ash forest phases for growing seasons in 2000 and 2001.

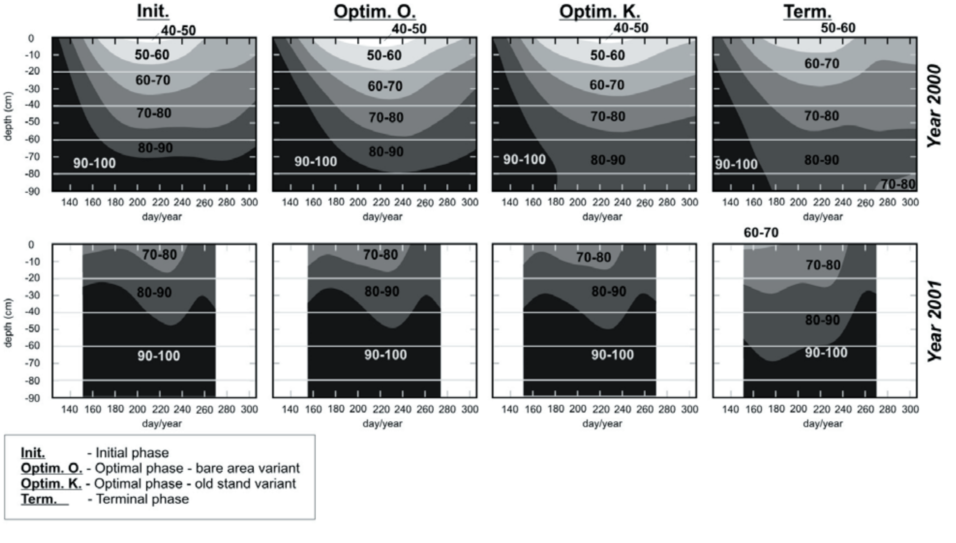

Fig. 2. Dynamics of soil water saturation degree in different developmental phases of ash forest for the vegetation period in 2000 and 2001.

T a b l e 3. Results of ANOVA with repeated measurements (MODEL 1) and Tukey post hoc test for phases in 2000 and 2001.

	2000 year						2001 year					
Depth (cm)	Phase		Time		Phase * Time		Phase		Time		Phase * Time	
	F	p	F	p	F	p	F	p (post hoc)	F	p	F	p
-5	2.58	0.149	112.33	**< 0.001**	4.18	**< 0.001**	2.03	0.212	35.94	**< 0.001**	1.93	**0.003**
-15	1.46	0.316	55.14	**< 0.001**	2.38	**< 0.001**	1.18	0.394	27.59	**< 0.001**	1.06	**0.402**
-25	0.62	0.63	39.50	**< 0.001**	1.53	**0.013**	7.71	**0.018 (1.2.3) (4)**	49.03	**< 0.001**	2.46	**< 0.001**
-35	0.20	0.891	29.80	**< 0.001**	1.28	0.096	14.17	**0.004 (1.2.3) (4)**	26.63	**< 0.001**	2.75	**< 0.001**
-45	0.12	0.947	28.29	**< 0.001**	1.57	**0.009**	34.41	**< 0.001 (1.2.3) (4)**	41.01	**< 0.001**	3.59	**< 0.001**
-55	0.03	0.991	16.11	**< 0.001**	1.21	0.158	17.98	**0.002 (1.2.3) (4)**	24.24	**< 0.001**	3.20	**< 0.001**
-65	0.74	0.565	14.45	**< 0.001**	1.40	**0.038**	21.9	**0.001 (1.2.3) (4)**	14.28	**< 0.001**	3.77	**< 0.001**
-75	2.31	0.176	10.30	**< 0.001**	1.70	**0.003**	8.69	**0.013 (1.2.3) (4)**	9.36	**< 0.001**	3.75	**< 0.001**
-85	2.02	0.213	16.77	**< 0.001**	3.21	**< 0.001**	9.84	**0.009 (1.2.3) (4)**	5.04	**< 0.001**	4.12	**< 0.001**
Water content to a depth of 90 cm	3.72	0.08	80.99	**< 0.001**	2.05	**< 0.001**	133.24	**< 0.001 (1.4) (2.3)**	56.39	**< 0.001**	3.82	**< 0.001**

Notes: F – F value, p – probability, 1 – initial phase, 2 – optimal phase (bare area variant – O), 3 – optimal phase (old stand variant – K), 4 – terminal phase

T a b l e 4. Results of ANOVA with repeated measurements (MODEL 2) and Tukey post hoc test for phases in 2000.

2000 year		Phase		Depth		Phase * depth	
Date	Day of the year	F	p (Post hoc)	F	p	F	p
03.05.	124	7.19	**0.021 (1,2,3) (2,4)**	5.39	**< 0.001**	1.5	0.114
11.05.	132	51.84	**< 0.001 (1) (2) (3) (4)**	20.26	**< 0.001**	3.7	**< 0.001**
18.05.	139	6.52	**0.026 (1,2,3) (1,2,4)**	48.81	**< 0.001**	0.75	0.77
25.05.	146	2.91	0.123	50.68	**< 0.001**	1.24	0.254
01.06.	153	1.62	0.282	70.94	**< 0.001**	1.67	0.066
07.06.	159	1.55	0.296	124.13	**< 0.001**	1.72	0.054
15.06.	167	0.44	0.73	122.55	**< 0.001**	1.53	0.104
21.06.	173	0.3	0.823	100.4	**< 0.001**	1.69	0.061
29.06.	181	0.15	0.929	61.37	**< 0.001**	1.05	0.431
06.07.	186	0.02	0.997	66.04	**< 0.001**	1.16	0.324
12.07.	194	0.02	0.997	56.16	**< 0.001**	1.16	0.321
20.07.	202	0.36	0.783	17.18	**< 0.001**	1.81	**0.04**
27.07.	209	0.03	0.99	50.16	**< 0.001**	1.21	0.285
03.08.	215	0.34	0.795	109.55	**< 0.001**	1.56	0.093
10.08.	222	0.54	0.673	75.59	**< 0.001**	1.03	0.45
17.08.	229	0.79	0.543	77.99	**< 0.001**	1.33	0.198
24.08.	236	1.03	0.443	68.39	**< 0.001**	1.34	0.189
31.08.	243	3.56	0.087	81.45	**< 0.001**	1.35	0.185
06.09.	249	2.18	0.191	45.79	**< 0.001**	1.33	0.195
14.09.	257	0.11	0.954	54.53	**< 0.001**	3.25	**< 0.001**
20.09.	263	0.73	0.572	6.94	**< 0.001**	4.05	**< 0.001**
27.09.	270	0.36	0.783	17.18	**< 0.001**	1.81	**0.04**
05.10.	276	0.79	0.544	14.46	**< 0.001**	2.98	**< 0.001**
12.10.	285	0.90	0.493	10.72	**< 0.001**	2.11	**0.014**
19.10.	292	2.48	0.158	539.26	**< 0.001**	1.72	0.056
26.10.	299	1.12	0.411	19.16	**< 0.001**	1.54	0.101
02.11.	306	2.27	0.181	20.43	**< 0.001**	1.48	0.123

Notes: F – F value, p – probability, 1 – initial phase, 2 – optimal phase (bare area variant – O), 3 – optimal phase (old variant – K), 4 – terminal phase

In 2000, no significant differences were found in soil water saturation at any depths for different phases (Table 3). The differences in the surface (5 and 15 cm) and in the deepest (75 and 85 cm) part of moisture measurements were relatively close to the point of significance. In terms of all phases, it is interesting that among individual measurement periods, the saturation degree differed significantly at all depths, which points to a time gradient in water dynamics. In terms of dynamics of soil saturation degree (phase x time interaction) at given depths, the phases differed from one another except at depths of 35 and 55 cm.

Based on variance analysis with repeated measurements and Tukey post hoc test for developmental phases of ash forests (Table 4), it is evident that there are statistically significant differences among individual phases in the degree of the entire soil profile saturation. On May 3rd, 2000 (124th day in the year), the initial phase and the variant of the optimal phase over a bare area had a considerably higher saturation degree than the terminal phase, but they did not differ from one another. Likewise, the soil in the terminal phase manifested no statistically significant difference in the saturation degree from the soil in the optimal phase variant in the old stand. On the 131st day of measurement, all phases (and variants) differed considerably, and saturation decreased from the initial to the terminal phase. On the 138th day of measurement, the soil in the terminal phase was significantly less saturated with water than the soil in the optimal phase over a bare area. As for the soil saturation gradient in the profile itself (0–90 cm) through the measuring period, the differences among ash phases were the most prominent in the second half of September. In other words, statistically significant differences were manifested among the phases in vertical anisotropy with regard to the investigated parameter.

In 2001, the soil of all developmental ash phases had a significantly higher water saturation degree during the measuring period compared to 2000. With regard to the entire measuring period, the water saturation degree in the terminal phase was significantly lower than that in the initial and the optimal phase at all measured depths except at 5 and 15 cm (Table 3). In terms of statistically significant saturation differences at different depths during the measuring period, time gradient is clearly distinct in this season, too. As for the dynamics of soil saturation degree at different depths, the phases differ mutually, except at a depth of 15 cm.

Based on variance analysis and Tukey test, differences were manifested in the water saturation degree among different phases through 5 measurements for both 2000 and 2001 (Table 5). In the second half of June (from the 165th to the 186th day in the year), the soil in the terminal phase was significantly less saturated with water than the soil in other phases. Interestingly, in the dry period of 2001 (23 August, 2001), there were significant differences in soil saturation in all phases and variants, except for the initial and terminal phase, which is an anomaly in terms of phase relationships in the largest part of the measuring period. As for the developmental phase x depth interaction, differences were manifested only on August 23rd and September 27th, 2001.

As for water content in the soil up to a depth of 90 cm in 2000, the developmental phases did not differ significantly (Table 3). Since water quantity varied considerably over time, the phases displayed statistically significant differences in terms of water quantity

T a b l e 5. Results of ANOVA with repeated measurements (MODEL 2) and Tukey post hoc test for phases in 2001.

2001 year		Phase		Depth		Phase * depth	
Date	Day of the year	F	p (Post hoc)	F	p	F	p
31.05.	152	1.32	0.351	49.47	**< 0.001**	0.7	0.829
07.06.	158	2.22	0.186	45.88	**< 0.001**	0.67	0.852
14.06.	164	33.56	**< 0.001 (1,2,3) (2) (4)**	16.91	**< 0.001**	1.37	0.176
20.06.	171	66.42	**< 0.001 (1,2,3) (2) (4)**	11.76	**< 0.001**	0.77	0.754
27.06.	177	15.2	**< 0.001 (1,2,3) (2) (4)**	46.73	**< 0.001**	1.66	0.068
05.07.	186	15.2	**< 0.001 (1,2,3) (2) (4)**	58.39	**< 0.001**	0.77	0.749
12.07.	193	3.48	0.091	29.67	**< 0.001**	1.31	0.209
27.07.	207	1.16	0.398	469.23	**< 0.001**	1.32	0.202
03.08.	214	0.15	0.928	136.58	**< 0.001**	1.2	0.293
09.08.	220	2.95	0.12	513.39	**< 0.001**	1.06	0.419
16.08.	228	4.21	0.063	302.75	**< 0.001**	0.83	0.689
23.08.	234	34.84	**< 0.001 (1,4) (2) (3)**	906.95	**< 0.001**	3.12	**< 0.001**
30.08.	241	0.68	0.549	356.23	**< 0.001**	1.05	0.435
06.09.	249				**< 0.001**		
13.09.	255				**< 0.001**		
20.09.	262	2.15	0.195	681.37	**< 0.001**	1.11	0.365
27.09.	270	3.95	0.072	547.37	**< 0.001**	2.3	**0.007**

Notes: F – F value, p – probability, 1 – initial phase, 2 – optimal phase (bare area variant – O), 3 – optimal phase (old variant – K), 4 – terminal phase

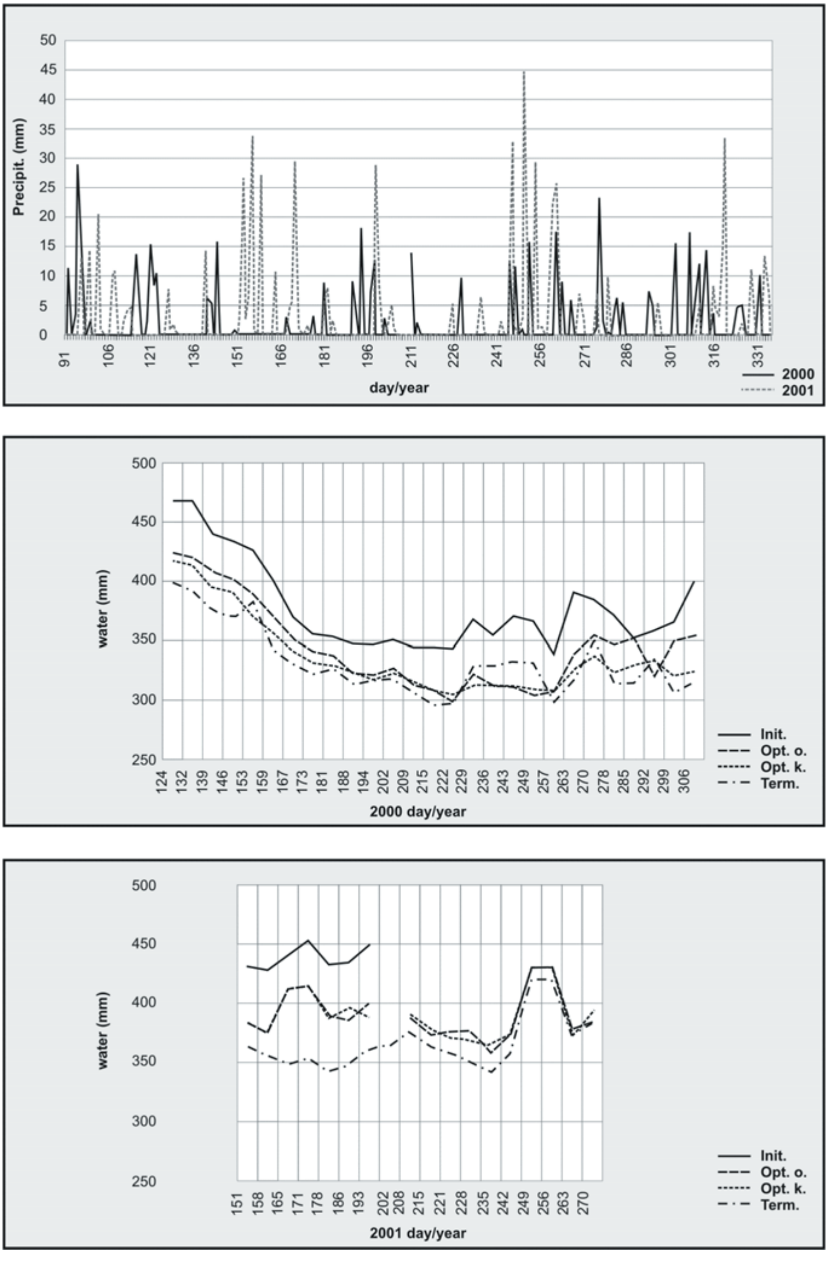

Fig. 3. Precipitation in Opeke meteorological station and water quantity in the soil to a depth of 90 cm in ash phases over the research period in 2000 and 2001.

dynamics up to the above depth. In 2001, except for water quantity dynamics, the developmental phases also mutually differed by water quantity to 90 cm deep (Table 3). The largest quantity of water was in the soil of the initial phase, and the smallest in the soil of the terminal phase. The optimal phase variants did not show statistically significant differences in this parameter. Fig. 3 illustrates the dynamics of total water quantity to 90 cm depth, with a big difference in the distribution and quantity of precipitation. Thus, in the station Opeke precipitation of 316 mm was recorded from April to September 2000 and of 555 mm in 2001. Water dynamics in the soil of ash phases (the same figure) indicates two completely different years in terms of hydrology. In 2000, the high water quantity in the profile resulting from the early spring period was maintained with lower precipitation quantities. However, higher quantities of precipitation in September (after the 245th day in the year) caused discontinuity in the slowly changing soil water quantity. This discontinuity was the least prominent in the optimal phase of the old stand. In 2001, the high quantity of precipitation in June and September was associated with very distinct discontinuity in the dynamics of water quantity in the soil to 90 cm depth. The graph shows the result from Table 3, which testifies to differences in the degree of soil water saturation in ash phases and to similarities in the optimal phase variants. In September, during abundant precipitation, the differences among the phases decreased, while those between the initial and the optimal phase almost disappeared.

Discussion

Profiling the ecological status of a narrow-leaved ash forest presupposes determining its edaphic conditions. These conditions are largely determined by water regime. Differentiating such an ecologically hard site as the site of narrow-leaved ash on the bottom forest boundary in Posavina is a highly complex endeavour. This is confirmed by our research, where characteristics of the degree of soil water saturation in three developmental phases of ash stands were studied in two hydrologically contrasting vegetation seasons (ecological diversity in ash stands also occurs in the non-vegetation season (Anić, 2001).

The degree of water content in the soil is regarded a very practical indicator of ash stand conditions, in which the soil in the lower part of the rhizosphere (in the initial phase it is within a depth of 1 m) is completely saturated with water over most of the year or the whole year. Anaerobiosis, or reduction conditions in the soil correspond to the soil saturation degree.

Clearly, soil water saturation corresponds on the one hand to the quantity of clay, and on the other hand it influences to the content and quality of organic matter and microorganism biomass. Eaton (2000) points out this parameter as a good predictor of soil quality in a forest site. In this case, the degree of saturation is used as an indicator of ecological relations in the ecosystem.

A relatively high degree of water saturation in the initial and the optimal phase could be linked to high soil capacity for water, very low capacity for air, and doubtlessly to a high level of water table, from which soil is capillary fed towards the surface.

In terms of the degree of soil water saturation, the terminal phase of ash forest is the most distinct, while in terms of total water quantity in the profile and its dynamics, the initial phase takes up the first place. This can be explained by less clay in higher microrelief positions and a texturally more homogeneous profile. On the other hand, the soil in the lowest microrelief positions in this range of narrow-leaved ash has the heaviest texture and is completely saturated with water over the whole year at least in the bottom part of the profile. Namely, in conditions of lowland floodplain forests, microrelief differences predispose the accumulation of powdery and colloid particles in microdepressions, which may have a decisive impact on the draining of soil water.

Characteristic trends in the degree of soil water saturation in the terminal phase of ash forests indicate relatively low hydropedological affiliation with the soil in the optimal and the initial phase. Distribution of soil water in this phase is the most favourable. Evaporation is low owing to complete crown closure and to the layer of shrubs and leaf litter in particular. Such conditions are even conducive to the occurrence of pedunculate oak and spreading elm, which contributes to the range of rhizosphere and better utilisation of water in the deeper parts of the profile. All this also points to the wide ecological amplitude of narrow-leaved ash, especially in relation to soil properties. This tree species has a pioneering role in bog conditions on vertic Gleysol with predominant anaerobiosis in deeper soil parts. The majority of ash stands in this area are linked to such clayly, ecologically heavy soils.

In spring, the soil in the optimal phase variant over a bare area is always more saturated with water than the soil in the old stand. Based on research in similar micro-relief conditions, Rampelbert et al. (1997) point to differences in soil moisture of the surface horizon. This is not the case with ash forests. More significant differences occur only deeper in the profile, with the initial and terminal phase being the most distinct.

The anomaly in the occurrence of significant differences in soil saturation among individual phases and variants may be ascribed to a specific random impact in the form of a shower. This impact explains the phenomenon occurring in the autumn of 2001. The site of the terminal phase is about 800 m away from the site of the initial and the optimal phase (the meteorological station is located approximately half way from each site). This could be the reason for the anomaly, considering precipitation dynamics and quantity in the meteorological station, as well as the time of year when local showers characteristically occur.

In completely different pedological and climatic conditions, Ladekarl (1998) ascribes the highest differences among measuring points after summer precipitations to the influence of spatial variability in interception and suction by the rhizosphere.

It is significant that there were no differences in the saturation degree decrease in the spring period of 2000 between the initial and the optimal phase in bare regeneration area, nor between the terminal and the optimal phase in the old stand.

The phases differed in the dynamics of the degree of soil water saturation at almost all depths. Despite the statistically significant differentiation in the dynamics of soil water saturation degree in the more humid growing season in 2001 (555 mm), it is less recognisable than in 2000. In the dry growing season of 2000 (316 mm), similarities in the dynamics of soil water saturation are clearly visible between the initial phase and the optimal phase in the bare regeneration area and between the terminal phase and the optimal phase in the old stand.

Interestingly, the highest saturation degree of the surface soil part in the summer period of 2000 occurred in the terminal phase of the ash forest. The reason probably lies in a multilayered canopy (trees, shrubs and ground vegetation) and in the relatively homogeneous soil in textural sense. Apart from this, species with deeper root systems also participate significantly in this developmental phase, so that desuction takes place over a larger rhizospheric area than in the initial and the optimal phase.

Conclusion

Based on research into the degree of soil water saturation in stands of narrow-leaved ash, the following conclusions may be drawn:

1. Field measurements were conducted in two hydrologically contrasting growing seasons. Nevertheless, the initial and the terminal phase of ash forest were differentiated most frequently in terms of the studied parameter.
2. In both measurement periods, the initial phase had the highest degree of water saturation, whereas the terminal phase had the lowest degree.
3. In conditions of a drier growing season (2000), the most favourable distribution of water in the soil (better aeration) occurred in the terminal phase.
4. Developmental phases differ from one another in the dynamics of soil water saturation at almost all depths. At the beginning of a drier growing seasons there was no difference between the initial and the optimal phase in the bare regeneration area, and between the terminal and the optimal phase in the old stand. Similarity between these pairs was evident throughout the growing seasons. In the year with more humid growing seasons, this differentiation regularity was hardly evident in terms of saturation degree dynamics.
5. The differentiation of ash developmental phases based on the degree of soil water saturation points to the wide ecological amplitude of narrow-leaved ash.

Translated by L. J. Vajagić

Acknowledgements

We express our gratitude to the company “Croatian Forests” Ltd. for their financial support of this research. We also thank Z. Turas on his assistance in field measurements.

References

Anić, I., 2001: The growing and regeneration of narrow-leaved ash *(Fraxinus angustifolia* V a h l.) in Sava river valey in Croatia. PhD thesis. Forestry Faculty, University in Zagreb. 197 pp.

Bell, J.P., Dean, T.J., Hodnett, M.G., 1987: Soil moisture measurement by an improved capacitance technique. Part II. Field techniques, evaluation and calibration. J. Hydrol., *93*: 79–90.

Brandelik, A., Hübner, C., 1996: Soil moisture determination – Accurate, large and deep. Phys. Chem. Earth, *21*: 157–160.

Bruckner, A., Kandeler, E., Kampichler, C., 1999: Plot-scale spatial pattern of soil water content, pH, substrate-induced respiration and N mineralisation in a temperate coniferous forest. Geoderma, *93*: 207–223.

Dean, T.J., Bell, J.P., Baty, A.J.B., 1987: Soil moisture measurement by an improved capacitance technique. Part 1. Sensor design and performance. J. Hydrol., *93*: 67–78.

Eaton, W.D., 2000: Microbial and nutrient activity in soils from three different subtropical forest habitat in Belize, Central America before and during the transition from dry to wet season. Appl. Soil Ecol., *16*: 219–227.

Ellenberg, H., 1979: Zeigenwerte der Gefässpflanzen Mitteleuropas. Verlag Goltze KG, Göttingen, 111 pp.

Evans, S.P., Thomas, R.M., Hollis, J.M., Brown, C.D., 1999: SWBCM: a soil water balance capacity model for environmental applications in the UK. Ecol. Modell., *121*: 17–49.

Härdtle, W., von Oheimb, G., Westphal, C., 2003: The effects of light and soil conditions on the species richness of the ground vegetation of deciduous forests in northern Germany (Schleswig-Holstein). For. Ecol. Manag., *182*: 327–338.

Hewlett, J.D., 1982: Principles of forest hydrology. The University of Georgia Press, Athens, GA, 183 pp.

Hilhorst, M.A., 1997: Dielectric characterisation of soil. Doctoral thesis. Wageningen Agricultural University, Wageningen, 136 pp.

Hörmann, G., Meesenburg, H., 2000: Die Erfassung und Modellierung des Wasserhaushaltes im Rahmen des Level-II-Programms in Bundesrepublik Deutschland. Forstarchiv, Hannover, *71*: 70–75.

Ladekarl, U.L., 1998: Estimation of the components of soil water balance in a Danish oak stand from measurements of soil moisture using TDR. For. Ecol. Manag., *104*: 227–238.

Likens, G.E., Bormann, F.H., Pierce, R.S., Eaton, J.S., Johnson, N.M., 1995: Biogeochemistrty of a forested ecosystem. Springer, New York, 146 pp.

Mallants, D., Mohanty, B.P., Jaques, D., Feyen, J., 1996: Spatial variability of hydraulic properties in a multilayered soil profile. Soil Sci., *161*: 167–181.

Ponizovsky, A.A., Chudinova, S.M., Pachepsky, Y.A., 1999: Performance of TDR calibration models as affected by soil texture. J. Hydrol., *218*: 35–43.

Rampelberg, S., van der Aa, B., Deckers, J., 1997: Soil morphology and soil water regime of loess soils under oak in the Meerdaal forest, Belgium. Agric. For. Meteor., *84*: 51–59.

Rawls, W.J., Gish, T.J., Brakensiek, D.I., 1991: Estimating soil water retention from soil physical properties and characteristics. Adv. Soil Sci., *9*: 213–234.

Schume, H., Jost, G., Katzensteiner, K., 2003: Spatio-temporal analysis of the soil water content in a mixed Norway spruce (*Picea abies* (L.) K a r s t.) – European beech (*Fagus sylvatica* L.) stand. Geoderma, *112*: 273–287.

Seyfried, M.S., Murdock, M.D., 2001: Response of a new soil water sensor to variable soil, water content, and temperature. Soil Sci. Soc. Am. J., *65*: 28–34.

Sokal, R.R., Rohlf, F.J., 1994: Biometry: The principles and practice of statistics in biological research. W.H. Freeman & Co., New York, 887 pp.

Strohbach, B., Degenhardt, A., 1999: Bodenhydrologishe Untersuchungen auf Level-II-Standorten in Brandenburg. Beiträge f. Forstwirtschaft und Landschaftsökologie, Berlin, 33: 114–117.

Veldkamp, E., O´Brien, J.J., 2000: Calibration of a frequency domain reflectometry sensor for humid tropical soils of volcanic origin. Soil Sci. Soc. Am. J., *64*: 1549–1553.

Wessolek, G., 2001: Bestimmung von Wasserhaushaltskomponenten in Waldökosystemen. Probleme und Erfahrungen. Beitr. Forstwirtsch. Landschaftsökol., *35*: 2–4.

Received 2. 5. 2005