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Effects of varying doses of Frisol on European ash (*Fraxinus excelsior* L.) planted on spoil banks

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ABSTRACT: Frisol forte (FR F) and Frisol active (FR A) are slow-acting organic fertilisers recommended for reclamation and revitalisation of undeveloped soils and degraded areas. Tentative results of experiments carried out with these products on spoil banks in the CR showed controversial reactions of plants – on the one hand a high mortality of seedlings and a very good growth on the other. Reasons for these disproportions projecting themselves into the welfare of woody plants probably lie in an incorrect dosage of products. Thus, a special long-term experiment was established with the objective to find an optimal dosing to be used in practice for the reclamation process on spoil banks. By the method of measuring and statistical evaluation of height and stem diameter growths it was discovered that the best results were achieved by the combined use of both products with a dosage in the range of 30–60 g FR F + 250 ml FR A/5 l of water/10 seedlings. The discovered dosage is lower than that indicated by the manufacturer and literature. The application of granulated FR F alone was not so effective. The best dosage in this case was also 60 g/seedling. A disadvantage of using the combination of both types of Frisol is that the water required for dissolving the FR A liquid concentrate is not always available in the location being reforested.

Keywords: Frisol forte; Frisol active; Silvamix forte; Cererit; European ash; organic fertilisers; fertiliser dosage; reclamation; spoil banks; survival rate and growth; welfare of plants

Frisol is the registered trademark for a method as well as components designed for biological reclamation and revitalisation of undeveloped soils and degraded areas. Frisol forte and Frisol active are the most frequently used components. As stated by their manufacturer (www.gebruederfriedrich.de), they are organic fertilisers with a long-term effect on soil improvement. Frisol forte contains 80% of dried and granulated biomass of soil microorganisms, e.g. *Penicillium chrysogenum*. The product contains 8% N, 2% P_2O_5, 2% K_2O, microelements and vitamins. It is recommended in doses of 100–300 g/m^2. Frisol active is a liquid product containing 50% of organic substances (sugar-phosphoramide), a total of 9% N and 11% P_2O_5. Its pH value is 1.5. The water dilution ratio is 1:20 and the manufacturer recommends doses of 50–150 g/m^2. The products were tested abroad on tree species set out in extreme climatic and soil conditions. Eckmüllner (1995) reported that Frisol improved the growth of spruce plants in dry locations with shallow soils. Fuchs (1995) stated that the optimal doses for reforestation in high-elevation areas were in the range of 100–150 g of Frisol F per seedling and 100 g of Frisol F per seedling planted in undeveloped soil. It is recommended to repeat fertilisation after two years. The manufacturer provides information on the use of Frisol in various countries (www.gebruederfriedrich.de). In the Czech Republic, Bulíř (2005) carried out experiments with these products for reclamation of spoil banks. The first results of these experiments showed that Frisol applied in higher doses and to heavier soils dramatically increased the mortality of seedlings. The same doses applied to lighter soils slowed down the survival process of seedlings, however, they improved their growth in the following years. The diverse reactions of plants to Frisol led to a special experiment, the objective of which was to look for an optimal dose of Frisol in respect of its effects on the survival rate and growth of seedlings.

Table 1. 1997–2005 average temperatures at Tušimice weather station

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
1998	0.6	4.4	4.5	10.2	14.8	18.0	17.8	17.8	13.3	9.2	1.2	–0.1	9.3
1999	1.2	0.2	5.3	9.3	14.3	15.9	19.7	17.5	17.2	9.1	2.4	1.4	9.5
2000	–0.1	3.7	4.9	11.2	15.6	18.4	16.3	19.0	13.8	10.6	5.0	1.4	10.0
2001	–1.2	1.0	3.9	7.7	15.2	15.5	19.4	19.2	11.7	11.8	3.3	–1.3	8.8
2002	0.5	4.4	4.8	8.3	15.5	18.1	19.1	20.0	13.2	8.0	4.5	–1.8	9.6
2003	–0.9	–3.2	5.3	8.3	15.3	20.6	19.2	21.0	14.3	5.5	5.0	–0.1	9.2
2004	–3.2	2.5	3.7	9.5	11.7	16.0	17.7	18.8	13.5	8.9	4.1	–0.1	8.8
Long-term average	–1.6	–0.5	3.5	7.6	13.1	16.0	17.9	17.3	13.4	8.0	3.4	0.4	8.2

This paper provides information on the results of the experiment.

MATERIAL AND METHODS

The European ash (*Fraxinus excelsior* L.) was selected as a model tree species. The experiment tested Frisol forte (FR F) and Frisol active (FR A). In addition to these two types of product, the pellet fertiliser Silvamix forte (SF) and combined mineral fertiliser Cererit (CE) were used to compare the effects of Frisol.

The experiment was established on Prunéřov spoil bank near the town of Chomutov. European ash seedlings (2/0) were pricked out in rows 2 m × 1 m in autumn 1997. The location is situated in the moderately warm B3 climatic zone, with a long-term average annual air temperature of 8.2°C, and an average annual precipitation level of 422 mm. The basic monthly data on temperatures and precipitation levels measured at the nearest weather station during the experiment provided by the Czech Hydrometeorological Institute in Prague is shown in Tables 1 and 2. The substrate was formed of grey clay with a heavy mix of porcelainite and gravel. The soil profile showed a grey clayish soil with no distinct fraction of humus at 0–2 cm; at 2–15 cm, there was a ferruginous-grey clayish soil with a distinct fraction of porcelainite and gravel with various grading, along with the coal detritus. Below this level, there was a mixture of ferruginous-grey up to ferruginous-white firm-to-loose clay, grey clay shale, and a minor fraction of coal

Table 2. 1997–2005 average precipitation level at Tušimice weather station

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
1998	22.7	6.2	26.9	10.1	12.0	64.4	61.5	27.0	79.6	78.0	33.2	11.1	432.7
1999	14.7	28.1	21.2	35.0	33.9	40.4	46.3	41.9	67.2	13.7	28.2	34.6	405.2
2000	22.4	11.0	67.0	27.1	34.6	32.5	79.7	53.9	32.8	53.4	35.9	8.3	458.6
2001	26.3	18.3	64.9	19.3	30.4	28.8	48.9	32.2	40.7	23.7	30.3	23.9	387.7
2002	11.0	36.1	17.4	17.7	73.5	58.0	56.3	127.5	56.3	38.8	86.2	57.4	636.2
2003	16.6	4.2	6.3	21.0	33.4	30.4	74.2	15.9	7.2	15.1	9.4	15.9	249.6
2004	45.8	15.0	10.1	11.5	89.0	37.8	67.8	35.2	31.7	28.5	37.2	16.5	426.1
Long-term average	23.1	22.1	22.5	26.5	44.9	56.5	46.5	62.9	38.5	27.2	30.0	25.3	422.1

Table 3. Physical properties of the substrate on Prunéřov spoil bank experiment location on May 28, 1998 (average of two probes)

Profile (cm)	Bulk density (g/cm^3)	Particle density (g/cm^3)	WPS (% vol.)	Porosity (% vol.)	AS (% vol.)
0–5	1.18	2.41	35.3	34.0	15.7
5–10	1.12	2.44	32.4	53.8	21.5
10–20	1.26	2.41	37.3	47.4	10.2
20–40	1.43	2.41	39.1	40.7	1.6
40–60	1.40	2.40	40.5	41.8	1.3

WPS – water pore space, AS – air space

Table 4. Chemical analysis of the substrate on Prunéřov spoil bank experiment location on May 28, 1998 (average of two probes)

Profile (cm)	pH	EC (mS/cm)	Contents of nutrients (mg/100 g of substrate)				
			$N\text{-}NH_4$	$N\text{-}NO_3$	P	K	Ca
0–20	6.1	0.89	5.0	3.5	1.0	20.5	1,095
20–40	6.1	0.92	3.3	1.0	1.0	17.5	915
40–60	7.1	1.11	19.0	1.3	1.0	19.0	1,555

EC – electrical conductivity

Table 5. Fertiliser doses for European ash on Prunéřov spoil bank

Variant	Dose
FR 1	FR F 30 g/seedling
FR 2	FR F 60 g/seedling
FR 3	FR F 120 g/seedling
FR 1 A	FR F 30 g/seedling + FR A 250 ml/5 of water/10 seedlings
FR 2 A	FR F 60 g/seedling + FR A 250 ml/5 l of water/10 seedlings
FR 3 A	FR F 120 g/seedling + FR A 250 ml/5 l of water/10 seedlings
SF	40 g/seedling = 8 pellets
CE	15 g/seedling
CO	control – without application

detritus. The substrate physical and chemical properties analysed according to Novák in Valla et al. (1980) and Soukup et al. (1987) at the beginning of the experiment are shown in Tables 3 and 4.

A randomised block design with four replications was used on the experimental plots. Ten seedlings were planted on each plot (experimental variant). All products were applied to plants in spring 1998, six months after planting. The doses of single products are shown in Table 5. Granulated products (FR F, CE) were evenly scattered around each planting hole and then slightly forced into the soil with a hoe. Two SF pellets were put into four notches made in a regular pattern around the holes by the planter. Frisol active (FR A) was water-diluted and then applied to seedlings after the application of FR F. Until 2003, weeds around the plants were mown and the plants were hoed twice a year, and in autumn the plants were treated with a repellent protecting them against animals. Moreover, the ash plants were fertilised. NPK fertiliser dose 3 g/plant was used during hoeing in 2001 and the same kind of fertiliser dose 15 g/plant was used in 2004.

The method of measuring the total annual height and stem diameter growth at the end of each vegetation period was used to evaluate the effects of the products on plants. A measuring stick was used to measure terminal shoots. The stem diameter was measured with a slide gauge 5 cm above the root collar. The acquired data was analysed by two-way analysis of variance (ANOVA). Statistically significant differences were evaluated by Multiple Range Tests using the significance level $p < 0.05$. Statgrafic plus, version 1, programme was used.

RESULTS AND DISCUSSION

Survival rate of seedlings

The products were applied in spring 1998, half a year after planting. No mortality of plants was identified in the course and at the end of the vegetation period. The first losses were discovered in 1999, when animals destroyed two plants. In the following years, the number of living ash-trees dropped slightly – due to animals, and because some plants were destroyed by motor mowers while mowing weeds. After seven years, the mortality of tree plants was about 9% – see Table 6. However, the tested products in the doses used did not contribute to the mortality of planted seedlings in any case. Mortality was neither caused by extraordinarily warm and dry April and May in 1998 (Tables 1 and 2), when the fertilisers were applied to young ash-trees or when they started taking effect on them. From this aspect, the tested doses can be considered suitable for and quite harmless to the healthy development of plants. Observations of mortality criteria confirmed earlier findings (Bulíř 2005) – the application of Frisol in lower doses or within a certain time after planting was more ben-

Table 6. Prunéřov spoil bank – numbers of living ash-trees in selected variants

Variant		1998 spring	1998 autumn	1999	2000	2001	2002	2003	2004	(%)
FR 1		40	40	40	40	38	38	37	37	92.5
FR 2		40	40	40	40	39	39	39	39	97.5
FR 3		40	40	40	40	37	37	36	36	90.0
FR 1A		40	40	40	40	35	35	35	35	87.5
FR 2A		40	40	40	40	38	38	38	38	95.0
FR 3A		40	40	39	39	36	36	36	36	90.0
SF		40	40	39	39	36	36	36	36	90.0
CE		40	40	40	40	38	38	38	38	95.0
CO		40	40	40	40	36	36	34	34	85.0
Total	abs.	360	360	358	358	333	333	329	329	91.4
	%	100.0	100.0	99.4	99.4	92.5	92.5	91.4	91.4	

eficial for plants because it caused neither waning of young seedlings nor prolonged planting shock.

Growth parameters

The basic growth parameters of ash-trees indicating the effects of various doses of Frisol in 1998–2004 are shown in Tables 7 to 9. The effects of the various doses and the combination of two types of Frisol on height growths manifested themselves with a higher statistical significance in the second year after the application. The longest average terminal shoots were measured for the combination of both granulated (FR F) and liquid (FR A) Frisol. This trend was even apparent in the third year, although the length of growths declined. Then, the dose of FR F 30 g + FR A 250 ml/5 l of water/10 seedlings showed itself the best of three such combinations. The growth effect of different doses of granulated FR F was lower and statistically significant only for the dose of 60 g/seedling. The pellet SF fertiliser increased the statistical significance of the better growth in the second year only, however, the growths were lower in comparison with the FR combinations. In the following years, the statistical significance of ash-trees treated with SF never surpassed the annual growth of terminal shoots of the control plants. The same also applied to ash-trees on the CE-treated plots, whose growth statistical significance never surpassed the growth of ash-trees on the control plots. The growth of terminal shoots in 2000 was low in all the variants (Table 7). It was probably caused by higher temperatures between April and June (during intensive growth) and by low precipitation – see Tables 1 and 2. Substantially better growth was measured in 2001 although the precipitation levels were low. The effect of the spring fertilisation with mineral NPK was evident on plants in all the variants. The ash-trees treated with the combination of FR F and FR A had the longest growths, becoming statistically significant for the dose of 60 g of FR F and 250 ml of FR A. This also occurred in 2004 after another additional fertilisation (Table 7).

The criterion of the overall growth of plants (Table 8) documents the fact that the combinations of both types of FR are the most effective. Before the ad-

Table 7. Terminal shoot height growths (cm) on ash-trees in 1998–2004

Variant	1998	1999	2000	2001	2002	2003	2004
FR 1	5.3 a	4.4 de	1.9 cd	6.1 ab	2.0 c	5.6 ab	13.4 a
FR 2	5.6 a	6.6 bc	2.8 bc	7.2 ab	3.3 abc	5.3 ab	9.1 ab
FR 3	5.9 a	4.8 cde	2.5 bcd	6.5 ab	3.3 abc	4.1 ab	6.6 b
FR 1A	4.5 a	9.1 a	4.1 a	7.2 ab	5.3 a	6.0 ab	11.2 ab
FR 2A	6.1 a	7.8 ab	2.7 bc	8.9 a	4.4 ab	6.9 a	11.2 ab
FR 3A	5.6 a	8.0 ab	3.5 ab	8.0 ab	3.8 abc	3.4 b	8.6 ab
SF	5.6 a	5.0 cd	2.5 bcd	6.4 ab	2.3 bc	3.4 b	9.9 ab
CE	5.2 a	4.5 cde	1.9 cd	6.1 ab	4.0 abc	4.5 ab	9.0 ab
CO	4.8 a	2.8 e	1.4 d	5.0 b	1.8 c	3.7 ab	6.5 b

Table 8. Overall height (cm) of European ash-trees in 1998–2004

Variant	1998 spring	1998 autumn	1999	2000	2001	2002	2003	2004
FR 1	40.0 a	45.3 a	49.7 ab	51.6 ab	57.7 ab	59.7 bc	65.3 ab	78.7 ab
FR 2	39.7 a	45.2 a	51.7 a	54.5 a	61.7 a	65.0 ab	70.3 a	79.3 ab
FR 3	38.1 a	44.1 a	48.8 ab	51.3 ab	57.8 ab	61.1 abc	65.2 ab	71.8 bc
FR 1A	37.9 a	42.4 a	51.4 ab	55.6 a	62.8 a	68.0 a	74.0 a	85.3 a
FR 2A	37.5 a	43.7 a	51.5 a	54.2 a	63.1 a	67.4 a	74.3 a	85.5 a
FR 3A	37.3 a	43.0 a	51.0 ab	54.5 a	62.5 a	66.3 ab	69.6 a	78.3 ab
SF	40.2 a	45.8 a	50.8 ab	53.2 ab	59.5 ab	61.8 abc	65.2 ab	75.1 abc
CE	39.3 a	44.4 a	49.0 ab	50.9 ab	57.1 ab	61.1 abc	65.6 ab	74.6 abc
CO	39.4 a	44.1 a	47.0 b	48.3 b	53.4 b	55.2 c	58.9 b	65.3 c

ditional fertilisation was applied in 2000, the highest plants were on plots dosed with 30 g FR F + 250 ml FR A. The remaining variants with FR combinations also had a statistically significant height in comparison with the control plants. The joint FR combinations held the first position in terms of height till the very end of the experiment, whereas there was no practical growth difference between the dose of 30 g FR F + 250 ml FR A and that of 60 g FR F + 250 ml FR A. Of all the tested doses, the mentioned ones proved to be the best. Ash-trees with this treatment surpassed the height of control plants by 20 cm in seven years (31%). When granulated FR F was applied alone, the dose of 60 g per plant showed itself the most statistically effective during the whole experiment. No higher or lower doses were demonstrative. The experiment proved that even lower doses than those recommended for extreme conditions, e.g. Fuchs (1995) and the manufacturer (www.gebruederfriedrich.de), are good for the growth of plants in anthropogenic soils.

A statistically significant improvement of diameter growth as well as of height growth occurred in the second year after the application of products (Table 9). The best results were achieved with combinations of both types of FR. The best stem diameter growth of plants on these plots was maintained till the end of the experiment. The measurement differences between single doses were only negligible. It means that even lower doses of 30 g or 60 g FR F + 250 ml FR A are sufficient for stems to keep growing well and thicker. The dose of 120 g FR F + 250 ml FR A shows itself to be a luxury. The stem growing of plants treated with the pure granulate (FR F) was slightly slower in comparison with the combinations. The statistical significance of the better stem growing is apparent only with the dose of 60 g FR F. Roughly the same effect was identified on the plots treated with SF. The fertilisation with CE had no impact on the stem growth. The effect after the additional fertilisation with NPK in 2001 and 2004 was not so spontaneous as it was in the case of height growths.

CONCLUSION

The long-term experiment established on Prunéřov spoil bank with the objective of determining the

Table 9. Overall stem diameter (mm) of European ash-trees in 1998–2004

Variant	1998 spring	1998 autumn	1999	2000	2001	2002	2003	2004
FR 1	6.2 b	6.7 abc	7.9 b	9.5 bcd	9.7 bcd	11.6 bc	12.9 bcd	16.8 a
FR 2	6.8 a	7.0 a	8.9 a	10.3 ab	10.7 ab	12.7 ab	14.4 a	16.7 ab
FR 3	6.2 b	6.5 abc	8.9 a	10.3 ab	10.5 abc	11.9 abc	13.0 bcd	15.0 bcd
FR 1A	5.9 b	6.4 bc	9.0 a	10.7 a	11.1 a	13.0 a	14.0 ab	15.9 abc
FR 2A	6.4 ab	6.9 ab	8.9 a	10.6 a	10.9 a	12.6 ab	14.5 a	16.7 ab
FR 3A	5.9 b	6.7 abc	9.2 a	10.7 a	10.9 a	13.0 a	14.0 ab	16.1 ab
SF	6.1 b	6.7 abc	8.4 ab	10.1 abc	10.5 ab	12.6 ab	13.5 abc	16.1 ab
CE	6.0 b	6.3 c	8.0 b	9.3 cd	9.6 cd	10.9 c	12.1 cd	14.4 cd
CO	6.2 b	6.7 abc	8.0 b	9.0 d	9.1 d	10.7 c	11.7 d	13.5 d

most suitable dose of Frisol to be applied half a year after planting demonstrated that the best results of influencing the growth were achieved by a simultaneous use of Frisol forte and Frisol active. The optimal dose per single plant ranges from 30 g up to 60 g FR F + 250 ml FR A/5 l of water/10 plants. The dose with a higher quantity of granulate (FR F) did not result in a stronger growth response in this combination. The statistically more significant height and diameter growths did not show themselves in the first year after the application, but as late as in the second year and they persisted during the whole experiment. After seven years the plants treated with the combination of both FR in the determined optimal dosing were one third higher than ash-trees on the control plots. The application of the granulated Frisol F alone shows a lower growth effect than the combination of the granulated and liquid FR. Statistically significant was only the dose of 60 g/plant. However, the advantage of FR F is better manipulation with doses and independence on water availability needed for FR A dilution. This fact may become crucial in the decision whether to use the FR A/FR B combination or FR F alone simply because the source of water need not always be available on the location to be re-forested. The growth effects of the SF and CE application never surpassed those of the FR combinations.

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Účinky rozdílných dávek Frisolu na jasan ztepilý (*Fraxinus excelsior* L.) vysazený na výsypkách

ABSTRAKT: Frisol forte (FR F) a Frisol aktiv (FR A) jsou dlouhodobě působící organická hnojiva doporučovaná pro rekultivaci a revitalizaci nevyvinutých půd a degradovaných stanovišť. Prozatímní výsledky experimentů s těmito prostředky uskutečněné na výsypkách v České republice ukázaly rozdílné reakce rostlin – na jedné straně vysoký úhyn sazenic, na druhé straně pak velmi dobrý růst. Příčiny disproporcí promítajících se do prosperity dřevin tkvějí patrně v nesprávném dávkování preparátu. Speciální dlouhodobý pokus si tedy kladl za cíl hledat optimální dávku pro praktické použití v rekultivačním procesu na výsypkách. Metodou měření a statistického hodnocení výškových a tloušťkových přírůstků bylo zjištěno, že nejlepších výsledků bylo dosahováno při kombinovaném použití obou preparátů a v dávce pohybující se v rozmezí 30–60 g FR F + 250 ml FR A/5 l vody/10 sazenic. Zjištěná dávka je nižší, než uvádí výrobce a literatura. Aplikace samotného granulátu FR F již tak efektivní nebyla. Nejlepší byla také dávka 60 g na rostlinu. Nevýhodou při použití kombinací obou druhů Frisolu je potřeba vody k ředění kapalného koncentrátu FR A, která nemusí být vždy na zalesňované ploše k dispozici.

Klíčová slova: Frisol forte; Frisol aktiv; Silvamix forte; Cererit; jasan ztepilý; organická hnojiva; dávky hnojiv; rekultivace; výsypky; ujímavost a růst; prosperita rostlin

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