Research paper

Erosion control properties of self-seeded forests that appeared in forestless areas of ravine-gully systems

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Abstract. During land unsoldering in Ukraine, so-called "self-seeded forests" appeared on lands that had not been used for agriculture for a long time. The purpose of the research is to find out the erosion control properties of self-seeded forests. Twelve locations of natural regeneration of various types of woody plants on the ravine-gully system of Cherkasy region were chosen as research sites. Self-seeded woods have a structure of different ages from 8 to 25 years. Most of them are represented by mixed stands, which increase their biological stability. They are better adapted to the current climate change. The formation of uneven-aged stands of natural regeneration with high resistance and erosion control properties was noted. According to the qualitative indicator of productivity, the natural regeneration turned out to be different, which was primarily caused by forest sites conditions, in particular, the steepness, the position on the slope, and the thickness of the humus horizon of the soil. The hardness of the soil was determined in the range from 17.1 to 19.0 kg/cm^2, which corresponds to an average loose state. The hardness of the soil in the control was 23.9 kg/cm^2, which corresponds to its compacted state. The water permeability of the soil under the studied stands was 11.1–27.3 (control – 8.9) mm/min, which characterizes it from the best to chasm. The obtained soil water permeability data confirm the rapid transfer of surface runoff to subsoil, which prevents the development of erosion processes. Natural regeneration on the slopes of the ravine-gully system is determined to be successful, although it requires considerable time for the formation of full-fledged plantations.

Key words: hardness, natural regeneration, surface runoff, water erosion, water permeability.

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Introduction

Much attention is paid to natural regeneration in the world forest science and practice. The natural ability of forest ecosystems to adapt to changing climatic conditions is generally recognized. In forestry practice, natural regeneration is usually considered as a means of reproducing forests and forest ecosystems in a natural way. However, so-called "self-seeded forests" appear in open areas that have not been cultivated for a long time. Such areas occurred during the dissolution of large collective farms and usually they are adjacent to forest areas. The area of self-seeded forests in Ukraine is about 500 thousand hectares. Until 2022, self-seeded forests were not legally enshrined in legislation, and only the Law "On Amendments to Certain Legislative Acts of Ukraine on Forest Conservation" took them into account as one of the ways to increase Ukraine's forest cover to an optimal level (Law No. 5650, 2022). The question of the definition of the term "self-seeded forest" arises. As a guide, you can take the definition of Food and Agriculture Organization (FAO) – "land plots with an area of more than 0.5 ha, covered with woody vegetation more than 5 meters high with a density of more than 10%, or covered with woody vegetation that is capable of reaching such indicators in the future" (FAO, 2016).

In connection with the adoption of the Law, there is a need to find out their condition, the success of growth, and for eroded ravine-gully areas, to assess the effectiveness of erosion control properties, which is an urgent task.

An analysis of 11 naturally regenerated stands in the pine forests of Northern Spain was performed by González-Martínez & Bravo (2001). Scientists noted the constant age distribution of natural regeneration, its early differentiation in height and high stability. The work of Chazdon & Guariguata (2016) is devoted to the definition and modelling of ecological and economic conditions where natural regeneration is a viable and favorable land use option. Researchers also justify the functioning of natural regeneration, monitoring, development of favorable incentives and standards that contribute to the management of naturally regenerating forests. Assessment of the success rate and state of natural regeneration of forest plantations on lands unsuitable for agricultural production in Chernihiv and Zhytomyr Polissia was carried out by Bilous (2006), Zakharchuk (2017), Khryk *et al.* (2020), and Zhezhkun (2022). In the publication of Hrynyk & Vasyliuk (2019) it is noted that the processes of natural afforestation of fallows are significantly extended in time and require special measures to promote natural regeneration. This will ensure its relatively quick canopy closeness and increase the area of mixed plantings of natural origin, resistant to fires and other negative factors. Maliuha *et al.* (2018) substantiated the possibility of using natural regeneration during the assimilation of eroded ravine-gully areas. They obtained positive results regarding the appearance, growth, and state of natural regeneration of Scots pine on the Pre-Dnieper eroded lands. Maurer (2007) considers natural renewal and its success as a key element and basis for optimizing the reproduction of Ukrainian forests based on ecologically oriented forestry. Zoning of the territory of Ukraine according to the potential success of natural seed renewal was developed by Maurer & Kaidyk (2016). Khryk *et al.* (2021) assessed the health condition of natural regeneration of Scots pine on the fallow lands of the Right Bank Forest Steppe of Ukraine. Therefore, some attention is paid to natural regeneration in general and in the ravine-gully areas in particular. However, the issues that are devoted to the performance of anti-erosion properties by natural regeneration (self-seeded forests) formed in the ravine-gully areas are insufficiently covered.

It is known that the natural factors of erosion development include a number of factors: climate, relief, soil and geological conditions, vegetation and human economic activity (Ochoa *et al.*, 2016; Hulshof & Spasojevic, 2020). Among the climatic properties, the amount and most importantly the intensity of precipitation is of significance. The steepness, length, shape and exposure of the slopes are the main characteristics to assess the influence of the relief. Among the soil properties, the following are distinguished: mechanical composition, structure, absorption capacity, humus content, soil moisture and density. Vegetation, in particular forest cover and its litter, is important. The emergence of self-seeding fundamentally changes the conditions: increase in hydraulic roughness, accumulation of litter, loosening of the soil by roots and its deep penetration, which contributes to the transfer of destructive concentrated surface runoff into the underground (Hofmeister *et al.*, 2019). The absorption capacity depends on the humidity and density of the soil, which makes it possible to control its water permeability and hardness (Alaoui *et al.*, 2018; Musienko *et al.*, 2020).

All the listed indicators are important, but to control the possible development of erosion processes, it is convenient to attribute and practically determine the hardness and water permeability of the soil.

The purpose of the research is to find out the erosion control properties of self-seeded forests in the ravine-gully areas as the main indicators of the anti-erosion resistance of forest stands.

Material and methods

The natural regeneration of various species of woody plants on the ravine-gully system of Cherkasy region was chosen as the object of the research. The Kaniv hydroforestry melioration station was created to carry out forest restoration and hydrotechnical works in the protective zone of the Kaniv Reservoir. Part of the lands of the ravine-gully system, as a rule, the territory of the slopes was not afforested. It remained as hay and pasture lands. Over time, natural regeneration of various species of woody plants took place in these areas. It turned out to be extremely viable in the conditions of eroded areas. All scientists agree that natural regeneration (self-seeded forests) is a way to obtain sustainable forest stands harmonized with the natural environment and one of the ways to increase forest cover in Ukraine.

In order to fulfill the program tasks, 10 test plots (TP) were laid on the spurs of the coastal ravines of the "Kaminna" gully and two TP on the slopes of the gully of the "Kruglyk" unit (Figure 1).

The area without forest (meadow) was chosen as the control plot. The ravine-gully system is located on the territory of the lands of the Bobrytsia community in the Cherkasy region. The location of the trial areas and their orthographic characteristics are given in Table 1.

Field work was carried out in the period of 2019–2022. In order to determine biometric indicators of natural regeneration, a

Figure 1. Spurs of the coastal ravines of the "Kaminna" gully (*a*) and "Kruglyk" unit (*b*).

Table 1. Location and orographic characteristics of test plots.

No TP	Geographic coordinates		Steepness of slopes %	Position on the slope	Humus horizon cm
	latitude	longitude			
1	49.836796	31.429695	13–14	medium	16
2	49.836483	31.428675	8–10	upper	12
3	49.836220	31.427577	6–8	lower	18
4	49.836417	31.426455	6–8	lower	17
5	49.836582	31.425408	6–8	lower	16
6	49.837010	31.424439	7–9	medium	14
7	49.837471	31.423673	7–9	upper	12
8	49.837997	31.422998	7–9	medium	13
9	49.838524	31.422295	7–9	upper	12
10	49.838952	31.421530	7–9	upper	12
11	49.805334	31.389030	5–7	upper	11
12	49.805618	31.388010	5–7	medium	15

continuous list of woody plants was compiled in the trial plots of 100 m^2 according to the method generally accepted in forest measurement (Yukhnovskyi *et al.*, 2013).

The performance of self-seeded forests erosion control properties was studied according to the most characteristic features – hardness and water permeability of the soil. The evaluation of erosion control properties of stands depends on the analysis of these indicators.

Soil hardness was measured with a Golubev's hardness tester. The number of measurements was 15 times. The water permeability of the soil was determined using steel cylinders with a diameter of 80 mm and a height of 100 mm. Each cylinder was buried in the soil half its height and the upper part (50 mm) was filled with water. The time of water penetration into the soil was measured with a stopwatch. That is, the absorption time of a 50 mm layer of water, which corresponds to torrential precipitation, was determined. The number of measurements was 10 times. Thus, water permeability was defined as the amount of water absorbed during the time in mm/min.

The type of soil and the thickness of the humus horizon were determined on the trial plots by the digging method (Petrenko *et al.,* 2014). The root system of self-sowing was studied by completely digging up the plants (Minder *et al.*, 2019, 2022).

During the processing of field materials, statistical calculations were carried out. Soil hardness and permeability statistics were obtained for ungrouped rows from a small number of observations (Senyo, 2007).

As mentioned earlier, 12 test plots were selected in natural self-seeded stands, which are both pure and mixed forest plantations (Table 2).

The undergrowth on the experimental sites is represented by *Quercus robu*r L., *Carpinus betulus* L., *Betula pendula* Roth., *Acer platanoides* L. (TP 1–6), *Robinia pseudoacacia* L., *Acer campestre* L., *Fraxinus excelsior* L., *Acer negundo* L. (TP 3–10) and fruit species carried by birds – *Prunus avium* L., *Malus sylvestris* Mill., *Pyrus communis* L. The undergrowth is usually sparse, 1–1.5 m in height. There is no undergrowth or understory on TP 11 and 12.

The understory species are *Corylus avelana* L., *Crataegus monogyna* Jacq., *Rhamnus frangula* L., *Ulmus parvifolia* Jacq., *Rosa canina* L. medium density.

Table 2. Biometric indicators of natural regeneration of woody plants on eroded ravine-gully lands.

No TP	Composition	Species	Age, years	Amount, pc.	Height, m	Diameter, cm	Components and their cover, %			Index of productivity
							undergrowth	understory	grass cover	
1	9Cb1Pt+Sa	*Carpinus betulus*	8–20	22	8.1	3.6	10	3	0	I[a]
		Salix caprea		1	9.0	10.0				I[a]
		Populus tremula		3	11.3	8.7				I[a]
2	10Bp	*Betula pendula*	10–25	54	5.2	9.0	15	5	0	III
3	6Pt4Bp+Cb, Fe	*Populus tremula*	10–25	13	13.6	14.3	18	7	3	I[a]
		Betula pendula		10	7.2	5.6				II
		Carpinus betulus		1	6.0	6.0				I[a]
		Fraxinus excelsior		1	6.0	4.0				I[a]
4	10Bp+Pt, Sc	*Betula pendula*	10–25	23	10.4	7.0	10	10	80	I[a]
		Populus tremula		1	6.5	6.0				I[a]
		Salix caprea		1	8.0	18.0				I
5	9Ps1Rp	*Pinus sylvestris*	15–16	38	4.1	6.4	20	15	65	I[a]
		Robinia pseudoacacia		6	3.5	8.0				I[a]
6	9Rp1Bp+Pc, Pt	*Robinia pseudoacacia*	20–25	15	7.6	11.9	6	3	40	III
		Pyrus communis		1	3.5	6.0				V
		Betula pendula		2	6.3	9.0				III
		Populus tremula		2	10.5	20.0				I
7	6Pt1Ps3Bp	*Populus tremula*	20–25	8	11	12.8	15	0	10	II
		Pinus sylvestris		1	8.0	14.0				II
		Betula pendula		4	7.9	8.0				II
8	6Bp1Pt3Rp	*Betula pendula*	20–25	8	10.2	12.3	5	9	100	II
		Populus tremula		2	12.5	15.0				I
		Robinia pseudoacacia		4	6.0	7.0				III
9	10Rp+Pa, Ps	*Robinia pseudoacacia*	20–25	13	4.2	4.5	6	0	100	IV
		Populus alba		1	13.0	22.0				I[a]
		Pinus sylvestris		1	5.5	22.0				IV
10	6Rp1Ps3Pt	*Robinia pseudoacacia*	20–25	8	8.9	8.5	8	0	100	II
		Pinus sylvestris		2	6.0	6.0				III
		Populus tremula		5	9.1	7.6				II
11	10Ps	*Pinus sylvestris*	10–17	56	5.1	5.9	0	0	0	IV
12	10Ps	*Pinus sylvestris*	15–20	33	6.0	7.5	0	0	20	III

Note: * Ps – *Pinus sylvestris* L.; Pt – *Populus tremula* L.; Pa – *Populus alba* L.; *Salix caprea* L.; Bp – *Betula pendula* Roth.; Fe – *Fraxinus excelsior* L.; Rp – *Robinia pseudoacacia* L.; Cb – *Carpinus betulus* L.; Pc – *Pyrus communis* L.

The living above-ground cover characterizes the sites: *Hypericum perforatum* L., *Lamium album* L., *Geum urbanum* L., *Achillea millefolium* L., *Bidens tripartita* L., *Agropyron repens* (L.) Beauv., *Carex stenophylla* L., *Avena fatua* L. Coverage from sparse to thick (80–100% on TP 3, 6, 8–10).

Gray forest loam soils are heavily washed away. All genetic subtypes of gray forest soils have a heavy loamy silty-coarse-grained mechanical composition and are characterized by a noticeable removal of silt along the profile. The largest removal of silt (13–37%) is inherent in the soils of the slopes of the gullies. The exposure of all plots is north-eastern. It is the most favorable for the appearance of self-sowing: it does not quickly dry out excessively, it retains moisture for a longer period, which ensures better rooting. Soil moisture at the time of the research was approximately the same at 9–10%, as the rainless period lasted more than three weeks. The content of organic matter in the control area (field) was 1.5% of humus. Natural renewal in such areas ensures an increase in the content of organic matter at the level of 1.8 to 2.1% of humus, depending on the age of self-sowing.

Results and Discussion

Characterizing the age parameters of test stands (Table 1), it is worth noting that plantations of different ages and high resistance are formed, which are able to effectively counteract erosion processes. According to the qualitative indicator of productivity (site index), the natural regeneration was different, which was caused primarily by forest vegetation conditions, in particular, the steepness, slope exposition, positions on the slope, and the thickness of the humus horizon of the soil (Table 1).

A 3-year-old Scots pine self-seeding is growing next to the TP 11 of the "Kruglyk" unit near the village of Bobrytsia (Figure 2). It is located in the upper part of a steep slope with a humus horizon thickness of 11 cm. The height of natural regeneration is 45 cm, root penetration depth – 15 cm, root neck thickness – 0.8 cm, current increment in height – 15 cm, crown diameter – 32 x 22 cm, diameter of the root system – 34 x 25 cm. A characteristic feature of the natural regeneration of Scots pine was the formation of curtains of different ages. Despite the fact that the stands have been formed as pure stands, due to the different age structure, they are stable.

Self-seeded Scots pine of 3 years growing near the TP 12 on the slopes of the "Kruglyk" unit illustrates Figure 3. It is located in the middle part of the slope with a humus horizon of 15 cm. At the same age, but in different growing conditions, it has better growth rates than the previous one. The height of the self-seeding is 56 cm, current increment in height – 17 cm, crown diameter – 33 x 23 cm, diameter of the root system – 35 x 26 cm, depth of penetration of the root system – 17 cm, thickness of the root neck – 0.9 cm.

It is known that the erosion control and water regulation role of forest plantations are due to the water permeability of the root layer and the roughness of the soil surface and depends on its properties, in-

Figure 2. Self-seeding of Scots pine on the steep slopes of TP–11: *a* – curtain placement of the self-seeding on the area; *b* – general view of a self-seeded stand; *c* – view of a 5-year-old plant.

Figure 3. Self-seeding of Scots pine on the steep slopes of TP–12: *a* – general view of a self-seeded stand; *b* – curtain placement of the stand on the area; *c* – view of a 6-year-old plant.

cluding physical ones, which are formed under the influence of root systems (Yukhnovskyi *et al.*, 2013, Minder *et al.*, 2019). Among the physical properties for research is the hardness of the soil, the statistics of which are given in Table 3.

In general, despite the different composition of self-seeded stands the soil hardness is in the range from 17.1 ± 0.20 to 19 ± 0.22 kg/cm^2. The values of such indicators by Kachynskyi's (1970) classification are referred to as a medium loose state and on the control – 23.9 ± 0.21 kg/cm^2, to compacted.

To evaluate the significance of the difference between the average values of the indicators the following pairs of test plots were selected: TP 1 and TP 9 with the same hardness; TP 2 and TP 4 – birch self-seeding, TP 6 and TP 9 – black locust stands; TP 5 and TP 12 – mixed pine plantation that have no significant differences. As well as TP 3 and TP 7 – poplar self-seeding; TP 11 and TP 12 – pure pine stand, which revealed a significant difference in the average values of soil properties. The evaluation data was put in Table 4. In addition, a comparison with the control was made.

Table 3. Statistics of soil hardness in experimental sites.

No TP	Age, years	Soil hardness measurement statistics					
		N	χ	σ	*m*	*υ*	*p*
1	8–20	15	18.5	0.88	0.23	4.74	1.22
2	10–25	15	17.8	1.01	0.26	5.67	1.46
3	10–25	15	17.1	0.76	0.20	4.45	1.15
4	10–25	15	17.5	0.84	0.22	4.83	1.25
5	15–16	15	17.7	0.98	0.25	5.52	1.43
6	20–25	15	17.8	0.94	0.24	5.29	1.36
7	20–25	15	18.8	0.84	0.22	4.47	1.15
8	20–25	15	18.1	0.93	0.24	5.16	1.33
9	20–25	15	18.5	1.09	0.28	5.92	1.53
10	20–25	15	19.0	0.92	0.22	4.80	1.13
11	10–17	15	18.7	0.49	0.13	2.63	0.68
12	15–20	15	17.4	0.68	0.16	3.93	0.90

Note: * *N* – number of repetitions, χ – average value, *σ* – average square deviation, *m* – error of the average value, *υ* – coefficient of variation, *p* – accuracy of the average value.

Table 4. Evaluation of the significance of the difference between the average values of hardness indicators.

Pairs of test plots	Number of degrees of freedom	Student's criterion $t_{0,05}$	Pairs of test plots	Number of degrees of freedom	Student's criterion $t_{0,05}$
1–9	26	0	6–9	26	1.883
2–4	26	0.884	5–12	26	0.975
3–7*	26	5.812	11–12*	26	6.007

Note: * The significance difference between the average values of indicators.

Table 5. Statistics of soil permeability in experimental sites.

No TP	Age, years	Soil permeability measurement statistics					
		N	χ	σ	m	υ	p
1	8–20	10	15.5	5.99	1.89	38.6	12.2
2	10–25	10	19.0	3.92	1.77	24.1	5.0
3	10–25	10	27.3	9.59	3.03	35.1	11.1
4	10–25	10	21.9	6.63	2.10	30.2	9.56
5	15–16	10	21.6	5.58	1.76	25.8	8.17
6	20–25	10	19.5	2.75	0.43	25.5	5.7
7	20–25	10	11.1	2.02	0.64	18.3	5.7
8	20–25	10	18.7	2.92	0.92	26.1	9.0
9	20–25	10	12.6	2.95	0.93	23.4	7.39
10	20–25	10	10.4	1.42	0.45	13.7	4.32
11	10–17	10	11.6	1.77	0.56	15.3	4.84
12	15–20	10	26.5	10.15	3.21	38.3	12.1

Table 6. Evaluation of the significance of the difference between the average values of permeability indicators.

Pairs of test plots	Number of degrees of freedom	Student's criterion $t_{0,05}$	Pairs of test plots	Number of degrees of freedom	Student's criterion $t_{0,05}$
1–9	16	1.373	6–9*	16	5.363
2–4	16	1.191	5–12	16	1.338
3–7*	16	5.227	11–12*	16	4.573

Note: * The significance difference between the average values of indicators.

A significant difference between the average values of the hardness indicators was found compared to the control of virtually all test plots.

For erosion control plantations, it is important to know their possibilities of absorption of liquid precipitation in the part of the surface runoff into soil horizon. The determined water permeability of the soil under the test plots plantations ranged from 11.1 ± 2.02 to 27.3 ± 3.03 and in the control 8.9 ± 2.04 mm/min (Table 5).

On the significance of the difference between the average values of indicators of soil properties among others, such as: projective covering of the soil with its plant components; steepness of slopes; the thickness of the humus horizon and the position of the areas on the slopes – the latter plays a decisive role (Table 6).

The location of the test plots on the slope significantly affects soil moisture. The upper parts have less moisture, and the drier soil, accordingly, has a greater hardness with a lower ability to absorb moisture.

The absorptive capacity of plantations according to the intensity of infiltration during the first hour will range from 545 to 1820 mm/h. Such results according to Kachynskyi (1970) make it possible to evaluate the water permeability of the soil from the best to chasm. Therefore, self-seeded forests contribute to the rapid transfer of surface runoff to soil flow, which prevents the manifestation of erosion processes.

Research has confirmed that soil hardness is quite clearly correlated with water permeability, having inversely proportional relationships (Figure 4). This dependence is described by Formula (1).

$$Y=1.181\,x^2 - 51.96\,x + 570.8 \quad R^2=0.958 \tag{1}$$

In this formula: y – water permeability of the soil, mm/min; x – soil hardness, g/cm^2; R^2 is a multiple correlation relation.

Both indicators significantly depend on the level of soil moisture. As the soil moisture level increases, its hardness decreases, which makes it possible for plants to develop a root system. But with excessive soil moisture, water permeability also decreases (Yukhnovskyi *et al.*, 2013).

Obtaining the maximum ameliorative effect from erosion control plantings of artificial origin is possible only if they are created from biologically stable and long-lasting species of woody plants. This is achieved by appropriate selection and mixing of woody plant species, taking into account their biological and ameliorative properties. Mandatory attention is paid to the forest vegetation conditions of the plots, the purpose of the plantings and

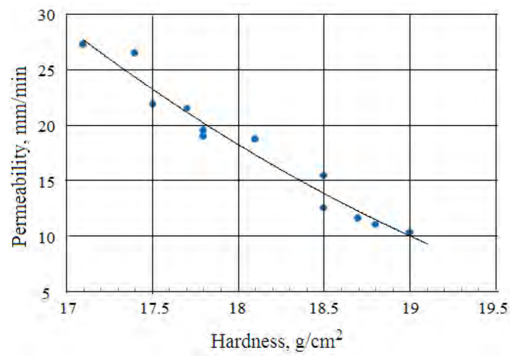

Figure 4. Dependence of soil water permeability on its hardness.

the specifics of their impact on the physical and water properties of the soil. Under such conditions, it is important to observe all technological operations for the creation of plantations, which is extremely difficult (Yukhnovskyi *et al.*, 2013). Self-seeded forests do not require such efforts, they organically adapt to the conditions of the natural environment which is confirmed by the results of these studies and other scientists (González-Martínez & Bravo, 2001; Maurer, 2007; Maurer & Kaidyk, 2016).

Conclusions

Self-seeded forests on the slopes of the ravine-gully system, which is located on the lands of the Bobrytsia community in the Cherkasy district of the Cherkasy region, were formed with different age structures. Their age ranged from 8 to 25 years. The vast majority of self-seeded forests are represented by a mixed composition of the main species: *Pinus sylvestris* L., *Betula pendula* Roth., *Robinia pseudoacacia* L. and *Populus tremula* L. This increases their biological resilience and better adaptability to current climate changes. Pure plantations are formed by *Pinus sylvestris* L. and *Betula pendula* Roth.

Natural regeneration on ravine-gully systems should be considered successful, although it requires considerable time for its formation.

The location of the test plots on the slope significantly affects soil moisture. The upper parts have less moisture, and the drier soil, accordingly, has a greater hardness with a lower ability to absorb moisture. The absorptive capacity of plantations according to the intensity of infiltration during the first hour will range from 545 to 1820 mm/h. Such results allow evaluating the water permeability of the soil from the best to chasm. Therefore, self-seeded forests contribute to the rapid transfer of surface runoff to soil flow, which prevents the manifestation of erosion processes.

Soil hardness is closely related to water permeability. The relationship between them is inversely proportional. Both indicators significantly depend on the level of soil moisture. As the soil moisture level increases, its hardness decreases, which makes it possible for plants to develop a root system. Therefore, self-seeded forests successfully perform erosion control functions, which are evaluated by indicators of soil hardness and water permeability.

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