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Possibilities of Using Small Tractors for Forestry Operations on Private Property

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Abstract

The difficulty of working conditions and the scope of forestry operations dictate the selection of suitable tractors. In areas with the prevailing private, small and fragmented forest property structure, the small machines may also be applied. Due to their technical characteristics, their scope of operation is often somewhat limited. Nevertheless, these machines can represent a reasonable choice for less demanding working conditions. They may be used for thinning operations or for assembling small loads, mostly in the downhill skidding operations. In regard to the uphill skidding, they may only be applied where the working conditions so allow. The test included AGT 835, a small agricultural tractor, featuring basic forestry upgrades. The test determined its usability and suitability for working operations according to three factors: tractive force, load size and longitudinal skidding incline. The spatial analysis was conducted in regard to the suitability of forests, where the AGT 835 tractor could be used. The share of forest is shown where the tractor could be successfully applied in accordance with its limitations. The study encompassed only private forests, namely the forest areas featuring terrain slope and stand conditions that allow the use of small tractors in the first place. The analysis showed a relatively frequent possibility of using small tractors, which are suitable on a small-scale forest property and which are generally considered as less suitable for forest operations.

Keywords: private forests, small tractors, wood skidding, limitations, possibilities of use

1. Introduction

Due to difficult working conditions (slope, load size, ground surface, weather conditions) forest operations are regarded as one of the most demanding aspects of forest management. Foresters need to adapt to these situations and apply different machines to transport wood from the point of cutting to the forest road. Apart from skidding, the transport of wood from harsh terrains is most often carried out with cable systems or tractors of varying power and characteristics. This is true for common forest operations executed by professional foresters and qualified and properly equipped contractors. They typically rely on heavy, modern machinery that can operate efficiently in a wide range of often very demanding working conditions.

However, the level of equipment used by the majority of private forest owners in Slovenia differs significantly. According to the Slovenian Forest Service (2012), 75% of Slovenian forests are privately owned. The average forest property is also small and fragmented, averaging just 2.3 ha per owner, with the annual cutting of 3 m^3/ha on average (Slovenia Forest Service 2012). This property size and the socio-economic characteristics of forest owners affect forest management intensity substantially (Medved 2000). The majority of owners conduct few, periodic operations in their forests. Usually they use tractors, mainly owned for agricultural use, which are upgraded for forest operations (Marenče 1997). These tractors differ in size, power, tractive force and other important technical features. Small tractors may also be used in forest operations; however they are less suitable for demanding working conditions. Nevertheless, they prove to be very useful, despite their limitations in less demanding working conditions.

Upgraded with additional forestry equipment, however, these tractors can be very useful on small forest tracts (Spinelli and Magagnotti 2012).

Apart from their technical abilities, the economic efficiency of these machines also contributes to the feasibility of such tractors. With a small capital investment, these small tractors can prove to be very cost effective (Moss and Hedderick 2012).

Tractors are not only suitable for skidding, but also in performing other operations. Cable systems can be applied in both directions of skidding (uphill, downhill), but the skidding costs are considerably larger compared to those of tractors for similar operations (Spinelli et al. 2010). Also, small mobile sawing systems are suitable for small-scale forests and can be coupled with tractor systems in a very interesting and usable system for small land owners, especially in terms of increased efficiency and decreased fuel consumption (Lasaux et al. 2009).

The search for advantageous technical and economical solutions has now spread to countries where the sustainable principle of forest management has been far less emphasized. The same is true of numerous transition countries that are now becoming aware of the importance of sustainability, professional work, and participation of local communities and small-scale forest owners in forest planning (Nijnik et al. 2009).

An entrepreneurial spirit is also frequently crucial in small-scale forestry, in wood and non-wood forest production as well as related services. Many owners do not view their forests only as a source of income attainable through proper machinery and harvesting. Forests often also have a symbolic meaning for them (Niskanen et al. 2007).

The concepts of small-scale forests, interrelations, forest dependence, and a close connection to agricultural operations represent important characteristics as well as differences within Europe. Many authors have tried to determine these relations by conducting surveys. Although they established numerous specific similarities, many differences persist among individual countries (Wiersum et al. 2005).

The issue of applying small machinery in forestry operations is not emphasized in a majority of countries with different ownership and land property structure, mainly due to different stand conditions, topography, and ownership. Conversely, this issue is very much present in countries characterized by predominantly privately-owned, fragmented forest land, as is also the case presented in this article. Moreover, as more countries face increased urbanization and fragmentation, as well as changing landowner objectives and interests, machinery for small-scale forest operations will become more critical.

2. Purpose of the research

Large, powerful machinery is often necessary, particularly in case of demanding working conditions. However, in areas with moderate terrain, gradual slopes, and smaller loads, small machinery can be very useful. Because of their technical characteristics, they have numerous use limitations, and thus their use is very limited. They could be used for thinning or small load skidding operations, mostly downhill, while uphill skidding can be accomplished only if conditions allow.

The use of these machines obviously calls for motivated forest owners, who manage their land despite its fragmentation and size. The focus was laid mainly on work-related technical specifications of small tractors, thus the issues pertaining to the economy of utilization of a certain type of machine in small-scale forests are not included in this article.

For this purpose, the AGT 835 T agricultural tractor was selected for analysis. The tractor is primarily designed for agricultural work, but for the study, it was equipped with modifications for work in light forest working conditions. Its suitability for this work was assessed by an analysis of its technical parameters, mainly the tractive forces it can generate during various skidding loads. Also the load size plays an important role, especially in uphill skidding operations. The study was limited to uphill skidding since it presents most difficulties in this type of operation. Downhill skidding was not addressed in this article. Specific issues examined in the study include:

The state of tractors on Slovenian farms – not only their number, but also the types of tractors by technical specifications (especially engine power). The number of machines with lower capabilities that are conditionally applicable for forest work were included;

The technical characteristics and performance of small tractors in specific operations – the study deals only with the technical part of the issue (tractive forces, load size in skidding operations); fuel consumption of individual tractor types has not been considered;

The extent of forest stands where the tractor with its limitations can be successfully utilized. That is, the study considers only private forests with terrain slopes and stand conditions that allow the use of these machines. Such information is critical, as it indicates the possibility of using small tractors, which are usually considered unsuitable for forest work. The information is also valuable for planning timber harvesting, market analysis, and the development of forest machinery market.

3. State of tractors in agricultural holdings

The data on the status and condition of tractors was acquired from the periodic registers of the agricultural census conducted by the Statistical Office of the Republic of Slovenia every 10 years. The data consists of information on tractors used mainly for agricultural purposes, but the same machinery when equipped with forestry equipment, is periodically used in forests. According to the periodic data (Poje 2006, 2008, 2010), the power of tractors has increased significantly in the past five decades, (from 19.6 kW in 1952 to 53.5 kW in 2002). The data also reveal that these tractors (some of which are very old) make in average only 280 working hours per year, i.e. less than one hour per day. These facts only further encourage the use of less expensive machinery with minimal technical capabilities for forest operations. It should be noted that this is limited only to cases where landowners conduct operations in their own forests and where the working conditions so allow. The same level of safety needs to be sustained regardless of equipment.

Other analyses of working mechanization (Heinimann 1999, Schrottmaier and Handler 2001, Jacke and Drewes 2004, Mago 2007, Hajdu and Mago 2007, Grgić 2009, Savelli 2010) establish tractor and other forestry machines characteristics and utilization potential. Mainly they mention the advanced age of the machinery, insufficient equipment for safe work, whereas in larger lands, where the work is more demanding, they are also equipped with more powerful and efficient machines (Šušnjar 2005, Poršinsky 2005). At the same time, the authors stress the issue of small farms, where there is less and infrequent work. In such cases the use of large and more efficient machines, usually employed in professional forest operations, is irrational mainly due to their costs. For this reason, small and seemingly less suitable machines could also be applied in such situations. This kind of machinery is very important in Slovenia according to the official data.

Poje (2012) indicates that almost 100,000 tractors of various powers and types were being used in Slovenia in 2010 according to the Statistical Office of the Republic of Slovenia. The data illustrate the diversity of tractors, farms mostly use tractors of low and mid-power range. There are almost 2/3 of 37 kW tractors, i.e. tractors that are not used in forest operations or are used only where the working conditions allow due to their limited power.

The AGT 835 T with its 26.4 kW engine power belonging to the class of most widely used tractors was selected for the analysis. According to its technical characteristics and power, this machine could also be used for some forest operations. This tractor was already discussed in previous articles (Jejčič et al. 2003, Košir et al. 2005, Marenče and Košir 2006a, 2006b, 2007).

This article aims to emphasize and show as follows:

⇒ load sizes that the tractor is capable of transporting to forest roads in uphill skidding operations;

⇒ inclines of skid trails that can still be managed;

⇒ tractive forces on wheels and the winch required for successful and safe timber harvesting. Previous studies have not addressed the detailed analysis of tractive forces in such machines;

⇒ facts and information representing a useful guideline to forest owners – especially those managing small forest land who can use tractors that are a favourite machinery among the forest owners.

The foregoing parameters can be of help in defining the tractor working range and solve the issue of its suitability and technical limitations in wood skidding operations. An important part of the analysis is also the information on stands and thus the scope of work that could be executed with this tractor in private forests. Thus, in our opinion, the answer to the question about the usability of these tractors, posed in this article, is important for everyday work at the farm. This is particularly true for fragmented and small-scale forests with predominant private ownership structure.

4. Research methods

The AGT 835 T tractor, designed for operations in small agricultural lands and vineyards, was additionally furnished with suitable and necessary forestry upgrades (front blade, rear blade with a winch, safety

Fig. 1 AGT 835 T tractor prepared for the test

Table 1 Technical characteristics, farm tractors AGT 835 T

Manufacturer	Agromehanika Kranj, Slovenia
Engine	Lombardini LDW 1503, 4 cylinders diesel
Displacement	1551 cm^3
Power	26.4 kW
Transmission	Mechanical
Tyres	750x16
Mass	1085 kg
Additional equipment	Safety frame, front blade, 30 kN winch Krpan, wheel chains

frame, wheel chains, one-drum winch). The machine is equipped with the four-wheel drive and designed for work in lighter working conditions and for skidding small loads (Fig. 1).

Some of its technical specifications are displayed in Table 1.

The skid trail, on which the test was conducted, was 191 m long, of concave shape, with the longitudinal incline constantly increasing from the forest road to reach its highest level of 27% in the upper portion (Fig. 2). The skid trail was divided into three sections according to its longitudinal incline (up to 10%, from 11 to 20%, over 20%). The results of the measurements (loads and tractive forces on wheels and winch) are presented separately, according to the longitudinal incline of the skid trail. All results and their analysis are shown for the uphill skidding operation, as this represents the most significant skidding problem and limitations when using such tractors.

In order to determine the soil humidity at the skid trail, the soil samples were regularly taken during the test days. The humidity changes during the day and for this reason the samples needed for analyses were taken twice a day at the characteristic points of the skid trail. The samples were taken in the morning before the start of skidding operations and also after the works. The values ranged between 36 and 42% during the test. Such values of a momentar soil sample humidity are mainly within the scope of the values usually established at the tractor skid trails (Robek and Medved 1999).

The measurements of the required tractive forces were conducted for the unloaded drive and with various load sizes. These were adjusted to the capacity of skidding means according to previous experience. The load always consisted of one, 8 m long, spruce tree

Fig. 2 Skidding at the most steep skid trail

with varying volumes (0.25 m^3, 0.50 m^3, 0.75 m^3, and 1.00 m^3). All loads were weighed in kilograms before the test. The measurement of technical parameters of every individual load size was executed without repetitions in this test.

Tests were conducted to establish the skidding limits of the tractor, i.e. the point at which the tractor was incapable of transporting the load due to load size or excessive longitudinal skid trail incline. The point was defined by the load that was too large for the tractor and with tractive forces that the tractor was capable to generate with its engine, but were nevertheless insufficient for skidding due to exceeding longitudinal incline and the resulting slip. Test results were used as indicators and criteria to assess the potential areas for the operation of this kind of machines.

The analysis of area suitable for the AGT 835 T tractor was conducted separately for four phytogeographical areas in Slovenia (Alpine, Dinaric, Coastal-Karts, Pannonian) (Zupančič et al. 1987). The analysis included only private forests with the areas (forest stands) suitable for the utilization of the analysed tractor on the basis of two main factors, slope of terrain and dimensions of trees. The terrain data were acquired from the Surveying and Mapping Authority of the Republic of Slovenia, Digital Terrain Models with 12.5x12.5 m resolution (GURS 2009), while the data on forest stands (ZGS 2013) were gathered from Forest inventory spatial database of forest stands, which encompasses 310,259 units in total, 211,942 of which are privately owned. The attributive part of the stand spatial record also includes data on the growing stock structure according to the average stand diameter at breast height (*DBH*) and is divided into five classes (I: 10–19 cm; II: 20–29 cm; III: 30–39 cm; IV: 40–49 cm; V: 50 cm or more) enabling a spatial breakdown according to stand diameter structure.

Suitable areas were determined with the assistance of Geographic Analyses System tools in the IDRISI software package (Eastman 1993) to classify private forests into four classes (suitable according to both criteria discussed above, suitable only from the aspect of stands, suitable only from the aspect of terrain slope, unsuitable according to both criteria).

5. Research results

5.1 Technical parameters in skidding with the AGT 834 T tractor

5.1.1 Load and the longitudinal skid trail incline

In order to determine the limit values of the tractor capacity, limitations were set in the scope of which skidding of selected loads could be performed. The load mass was gradually increased during the test (from 220 kg to 770 kg), while the skid trail itself with its concave shape and constantly increasing incline (up to 27%) made the work increasingly difficult.

Table 2 Skidding efficiency according to the longitudinal skid trail incline and load size

Load size	Incline of the skid trail, %		
	Up to 10%	11 to 20%	Over 20%
No load	✓	✓	✓
0.25 m^3, (220 kg)	✓	✓	✓
0.50 m^3, (464 kg)	✓	✓	✓
0.75 m^3, (657 kg)	✓	✓	✓
1.00 m^3, (770 kg)	✓	✓	STOP at 27%

Where:
✓ Tractor traversed the entire skid trail
STOP Tractor stopped at the specified level of incline due to overload

Working conditions (load, longitudinal incline) were selected to reach the tractor limits due to an overload. Skidding efficiency is shown in Table 2.

As expected, the tractor did not have any problems when empty (unloaded) or carrying light loads (up to 0.75 m^3). The skid trail with the biggest longitudinal incline of 27% did not represent any difficulty in these cases. Despite the increasing wheel slip (Marenče and Košir 2007), the tractor managed to complete the entire skid trail. In such analyses, the load size is mainly expressed by volume; its mass is also stated to additionally explain the level of difficulties related to conditions, especially in relation to the required tractive forces analysed in the second part of this article.

The tractor with the maximum load did not manage to complete the top section of the skid trail (27%). The test was stopped at the point when the wheel slip brought the tractor to a stop. Thus the limit was reached where the combination of 1 m^3 load and the longitudinal skidding incline of 27% did not allow further operation. Downhill skidding operations obviously have different limitations, but this issue is not the subject of this article.

5.1.2 Tractor tractive forces

Apart from the load size (in connection to the longitudinal skidding incline), the tractor tractive forces are those that set the limits and define the utilization of a certain machine. This article discusses only the uphill skidding where the level of difficulty is always the highest, especially if the tractor used for forest operations develops correspondingly lower tractive forces due to its lower engine power.

The value of the tractor tractive forces was acquired by measuring torques, with the assistance of dynamometers inserted between the axle and individual wheel (Fig. 3). The tangential force transferred to the ground via its rim was calculated, taking the wheel radius into account.

The tangential force was calculated as:

$$F_t = \frac{M}{r_d} \qquad (1)$$

where:

F_t tangential (circumferential) force;
M torque on the wheel axle;
r_d wheel radius.

The dynamic wheel radius was considered (Krpan 1962, Sever 1980). It is smaller than the theoretical one and depends on the wheel load, size and form of tire, tire pressure, type of surface, and velocity. The radius

Fig. 3 Prior to the measuring test of tractive forces

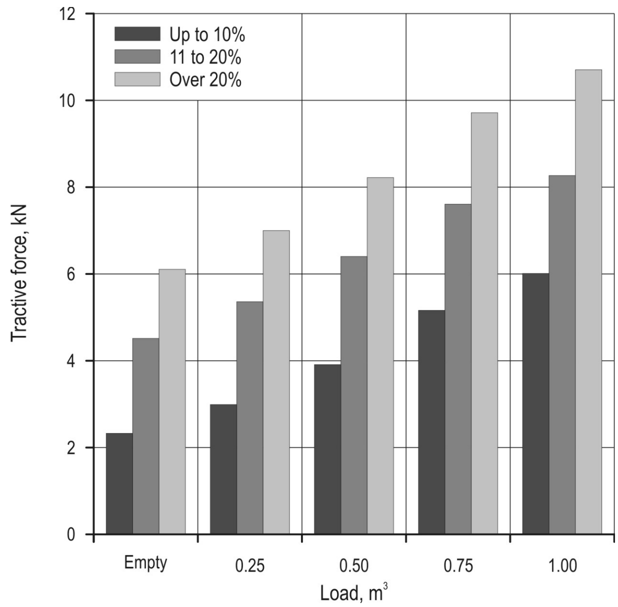

Fig. 4 Tractive forces on tractor wheels during uphill skidding

Fig. 5 Measurement of pulling forces on the winch of AGT 835 T

was measured at the skid trail section where the test was conducted. This measurement was performed under conditions that applied to the whole test (Jejčič et al. 2003, Marenče and Košir 2006).

The circumferential force on wheels is required to overcome the resistances occurring during the tractor movement and also to skid the load (Košir 1997). This study is mainly aimed at determining the quantity of force the tractor is capable of generating in different working conditions and able to transfer to the ground considering the increasing wheel slip. In other words, the study tries to establish the point where the conditions are too harsh for operation and the utilization of the tractor is not possible due to insufficient tractive forces. At the same time, the aim is also to establish the relationship between the force necessary for tractor movement and the efficient force needed for skidding.

The tractive forces on the wheels, which the tractor could generate during the test, are shown in Fig. 4. Expectedly, the lowest load on wheels is recorded during the unloaded uphill movement. The unloaded tractor with its mass of 1.1 t needs a tractive force of approximately 6 kN in the steepest section. By gradually increasing the load (from 0.25 m^3 to max 1.00 m^3) and the skidding incline, the need for higher tractive forces is also increasing. The most demanding part of the test is skidding the largest load (1.00 m^3) in the top and steepest part of the skidding trail, where the incline exceeds 20%. Here, the highest necessary tractive force for tractor movement and load skidding (almost 11 kN) was achieved. This is also the point that determines the capacity and thus the limitation and utilization of the tractor. This tractor cannot pass this combination of longitudinal skid trail incline and load.

The test also included the measurement of the necessary pulling force on the linkage, i.e. the winch cable. The front part of the load is usually raised from the ground during skidding. The measured force represents the actual resultant between its horizontal and vertical component. The vertical component represents the load mass at the rear part of the tractor. The research study focused mainly on the horizontal component, the part of the joint force that is actually needed for skidding. The change of the longitudinal skid trail incline and the load size also alters this force. Higher longitudinal incline and larger load call for the higher pulling force. The remainder is necessary for the tractor movement, i.e. to overcome the rolling resistance and the incline.

For this purpose, the rear board was equipped with the frame on which two devices were perpendicularly placed for pulling force measurement. By adjusting the height of the rear board, their horizontal and vertical positions are regulated (Fig. 5). This device was used to obtain the most realistic measurement of the horizontal force component on the winch, while not significantly altering the usual load position on the rear board.

The forces required only for load skidding are shown in Fig. 6. The load size was selected according to the expected performance of the tractor. All loads used in the test were weighed – their mass is shown in Fig. 6 above the columns representing pulling forces. The necessary forces do not exceed the value of 2 kN when applying the smallest load. By increasing the load and skidding incline, the forces increase and exceed the value of 4 kN in the most demanding section. This is also the highest value established in the test. The tractor stopped in this part of the skid trail.

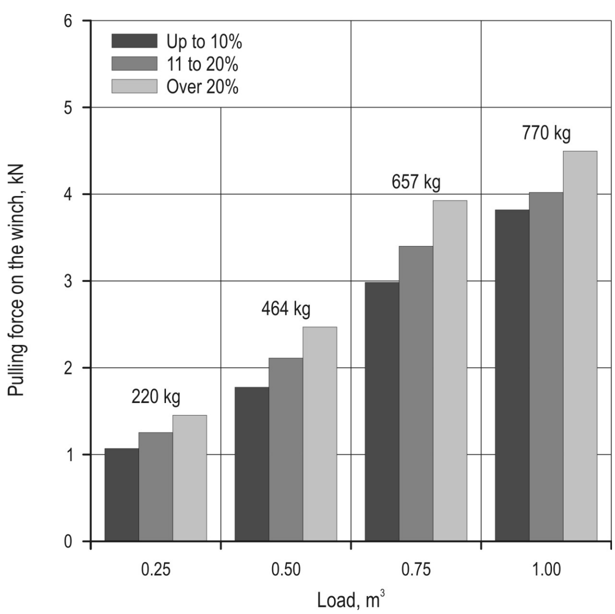

Fig. 6 Horizontal pulling force on the winch

Fig. 7 shows the relations between the total tractive force on tractor wheels and the force necessary only for skidding. In certain working conditions, especially in more gradual skid trail sections and with larger load, the necessary force for load skidding is higher than for the sheer movement of the machine.

In a similar way, the measured values can also be presented with the efficiency of rolling resistance η_f. Where (Sever 1984):

$$F_f = F_O - F_H \quad (2)$$

Where:

F_f rolling resistance force;

F_O circumferential (tangential) force of all wheels;

F_H horizontal component of the pulling force.

And the efficiency of rolling resistance (Sever 1985):

$$\eta_f = \frac{F_H}{F_O} = \frac{F_O - F_f}{F_O} = 1 - \frac{F_f}{F_O} \quad (3)$$

The term actually represents the ratio between the horizontal force on the winch necessary for load skidding and the total tractive force on tractor wheels. In other words: η_f represents the share required for skidding, while the rest is available for the tractor movement.

Table 3 Efficiency of rolling resistance η_f

Section	AGT 0.25 m³	AGT 0.50 m³	AGT 0.75 m³	AGT 1.00 m³
To 10%	0.36	0.45	0.58	0.64
11 to 20%	0.23	0.33	0.45	0.49
Over 20%	0.21	0.30	0.40	0.42

Table 3 shows that the tractor requires a higher force for its own movement; the exception is only the skidding of larger loads (0.75 m^3 and 1.00 m^3), where the tractor needs more than a half of the available force for skidding on the least steep section.

The above-stated data do not include wheel slip that always occurs during the tractor movement. The slip even deteriorates the efficiency of the machine in uphill skidding. Its influence is distinctively present especially in the top, the steepest skid trail section where the largest load was skidded. Thus, there is even less available tractive force for the movement of the machine (Table 4) in the most demanding conditions – only 25%. The data on wheel slip were not analysed in detail, since previous research addressed this topic (Marenče 2005, Marenče and Košir 2007).

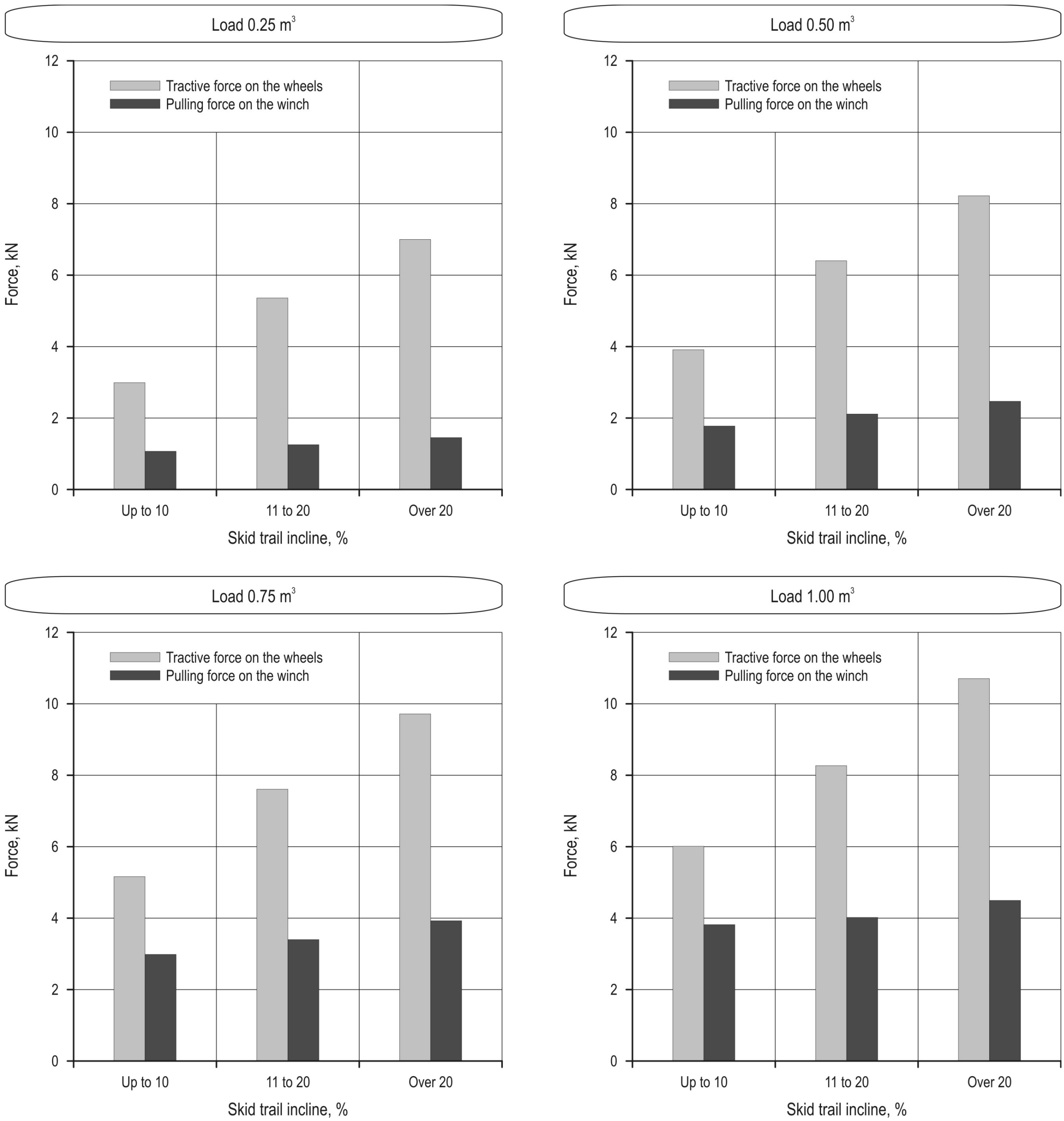

Fig. 7 Ratios between the total tractive force and the force on the winch

Hence, Fig. 8 shows only the data on the slip measured in the whole test.

Therefore, it is proper to also include wheel slip in the analysis of the actual available tractive forces of the tractor.

For this purpose the effects of wheels are expressed with the efficiency on wheel η_k. The η_k value actually

Table 4 Wheel efficiency η_k

Section	AGT 0.25 m^3	AGT 0.50 m^3	AGT 0.75 m^3	AGT 1.00 m^3
To 10%	0.34	0.43	0.53	0.58
11 to 20%	0.22	0.30	0.39	0.42
Over 20%	0.18	0.25	0.32	0.25

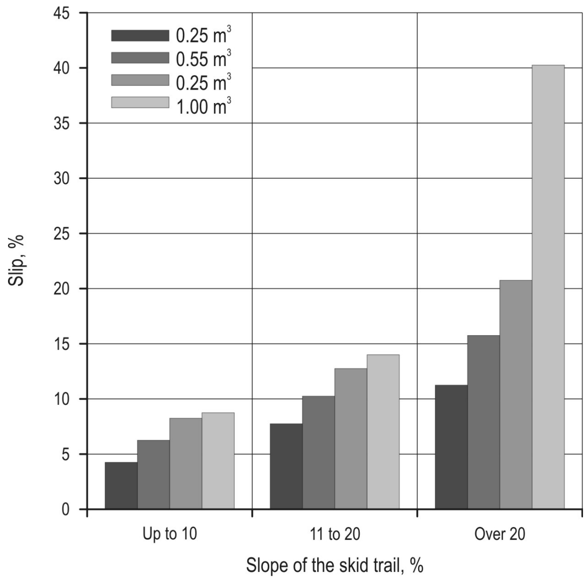

Fig. 8 Slip in relation to the skidding slope and load size

conveys the effect of rolling resistance reduced by the wheel slip value.

Therefore, the values in the table represent actual efficiencies or shares available for the tractor movement on the skid trail. An additional explanation is needed: in the last section, with the longitudinal incline above 20% and with the load of 1 m^3, the average slip of 40% was established. This value represents the skidding average for the last section before the tractor stopped. The value was used to calculate the average wheel efficiency in this section, which is 0.25. At the moment of the stop, the wheels turned without traction, the slip reached the 100% value, and there was no necessary wheel contact between wheels and the ground. This occurred at the 27% incline; the movement of the machine was not possible anymore. The occurrences in the last few meters before the stop are not analysed in detail in this discussion.

This analysis of tractive forces and loads can be very useful for assessing the suitability of small tractors for forest operations. The maximum limit of the tractor usability can thus be established: in this case this is represented in skidding up to approximately 20% inclines and with loads of up to 1 m^3 in size.

The article focuses on the second part of the issue: How many working sites of this type are actually present in private forests? This analysis follows in the next chapter. Both pieces of information are necessary to answer the key question: on how much area are tractors with limited technical capacity and proper forestry equipment able to operate in periodic operations in small-scale forests.

5.2 Selection and analysis of suitable areas

Several criteria and limitations were considered when establishing and selecting the operability areas for these machines. The analysis included only private forests, while the limitations incorporated the values established in the foregoing test. These values represent the limits these tractors cannot exceed due to their technical limitations. The values show the success of operations that include loads smaller than 1 m^3 and longitudinal skidding inclines up to 20%. Based on these limits, the analysis of all forest areas excluded those where such machinery cannot be used. The whole territory of Slovenia was divided into four areas that differ by terrain and stand conditions; the division according to phytogeographic regions was applied as the basis (Zupančič et al. 1987). Thus, the results of these analyses within Slovenia differ considerably by terrain difficulty and diverse stand conditions. By disaggregating the results of suitability for the AGT 835 T tractor into phytogeographic regions, the research has greater applicability beyond Slovenia.

Two limits were set in determining suitable areas:

⇒ the difficulty of terrain conditions was defined with the terrain slope limited to 20%; the test revealed that the tractor manages inclines up to this point and has no significant problems in skidding;

⇒ the stand conditions are defined by the average diameter at breast height; the limit was set at a diameter of 50 cm, as this dimension of properly bucked loads is considered appropriate for skidding operations.

The data are shown in Table 5. The analysis indicated that, when both limitations were strictly followed (slope up to 20% and diameter less than 50 cm), an average of 39% of the areas proved suitable. The set limitations exclude all other areas, due to exceeding incline or tree dimensions.

Table 5 Shares of suitable areas according to terrain and stand conditions

Region	To 20%		20 to 30%	
	DBH < 50	DBH ≥ 50	DBH < 50	DBH ≥ 50
Alpine	25%	5%	10%	5%
Dinaric	35%	15%	12%	8%
Pannonian	60%	13%	9%	4%
Coastal-Karst	43%	11%	11%	7%
Total	39%	8%	11%	5%

It was also interesting to alter the primary limits, or at least move them, and then compare the share of suitable areas. Here, two possibilities were considered:

⇒ allowing greater tree diameters (by bucking shorter but still permissible lengths of sorts this alteration is possible; the load does not exceed the specified size of 1 m^3),

⇒ allowing greater terrain slope (20 to 30%), in upslope skid trails skidding is still possible; the inclines do not exceed the value 20%.

By altering the limits, the shares of suitable areas also increase. If both limits were changed, the result would be 63% of suitable areas (Table 5).

The analysis of the Alpine region expectedly exhibited the most limitations and thus the smallest possibilities of using these machines in comparison to other parts of the country. The terrain slope is the primary reason for limiting the operations in this region. On the other hand, the results for the Pannonian part (NE of the country) are quite the reverse (Fig. 9).

6. Discussion

It should be emphasised that the AGT 835 T tractor is not designed for professional operations, but rather for occasional work in small-scale forests. Due to numerous limitations, presented in the analysis, it does not stand as a reasonable alternative to the machinery used in everyday forest operations. Working conditions are simply too demanding for these tractors to be suitable for the majority of working sites. On the other hand, these tractors are very common on private farms and private forests represent the highest share in Slovenia.

Owners of large farms and forest properties operate with larger and more powerful machines, which is necessary mainly due to the extent of work. The machinery can also be used in forest operations in various conditions. The work with these machines, mostly equipped with forestry upgrade, is easier, more efficient and most importantly safer. Furthermore, these machines can manage stands on steeper terrain and transport larger loads.

However, the use of smaller machinery for less demanding and infrequent forest operations can be more practical. In such cases, the forestry upgrade is simple and, therefore, also economically feasible. Previous research (Spinelli and Magagnotti 2012) offered similar solutions with additional winch and latching mechanisms. A smaller and properly equipped tractor can also be a good choice for operation in small-scale forests. In this study, the tractor was equipped with a simple single-

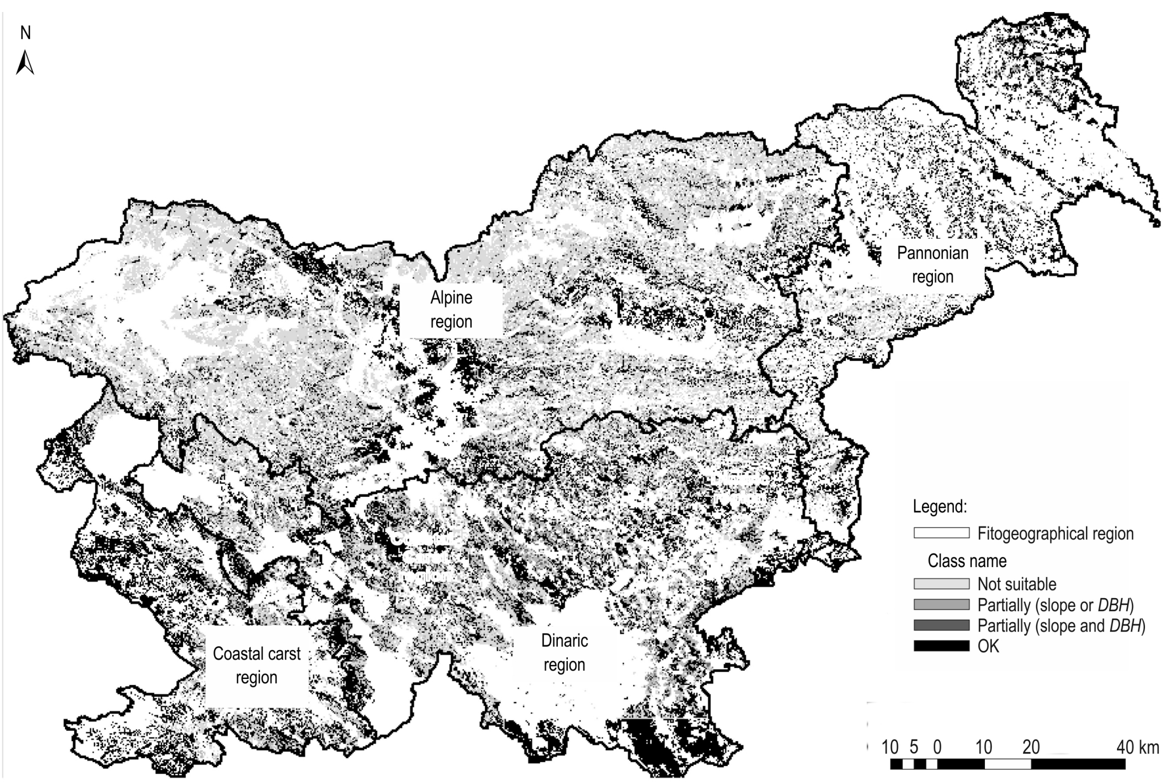

Fig. 9 Spatial distribution of all suitable areas (dot represents the selected forest stand location)

drum winch, as well as a rear board and a safety cabin. The skidding of smaller loads (up to 1 m^3) was analysed considering smaller engine power and uphill skidding.

The article does not deal with the option of using cable systems for skidding operations. In addition to small tractors, mini cableways, due to their lower operation costs, represent an additional option (Spinelli et al. 2010). They represent a good solution for skidding on steeper terrains, in terms of productivity as well as safety. Such technology could further increase the share of areas determined in this article as suitable for the use of small tractors. This is especially true for the Alpine region, where the analysed data showed that the terrain slope is the most prominent factor limiting the utilization of this technology.

7. Conclusion

The use of small tractors and a simple forestry upgrade is limited. Furthermore, forest operations, where such equipment is practical, are conducted only periodically and the scope of work is also small due to tract size. The economic returns for such instances is frequently questionable. In similar land conditions in other countries, some authors (Moss and Hedderick 2012) stress the importance of this segment of forest operations. That is why the selection of the machine and equipment is important. Simple, affordable and reasonably efficient and safe method of work provides acceptable solutions for small-scale forests also in economic terms.

Several studies (Wiersum et al. 2005) dealing with the topic of small-scale forestry within the European region show significant differences between countries. These are indicated in different private ownership structures, land sizes, economic dependence of income from forests. Many of them are not interested in this kind of work. The article shows the private land evaluation in Slovenia in order to assess the possibility of work in such ownership structure, stand and terrain conditions. According to the situation in Slovenia, it has been estimated that the approach analysed in the article can be considered as suitable, reasonable and executable at least for one part of forest owners. Two questions are relevant for them: in what working conditions can they use their machinery and what is the share of areas where the work can be actually executed. The article answers both questions.

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