The miniskidder ECOTRAC 55V can effectively replace the aggressive crawler tractors used in Alpine logging operations.

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Introduction

Despite the recent advances of industrial harvesting technology, forestry-fitted farm tractors are still the backbone of the Italian logging fleet (Spinelli and Magagnotti 2011a). Farm tractors are used for a variety of forest harvesting tasks, especially extraction (Picchio et al. 2009) and transport (Susnjar et al. 2008). Conversion to extraction work requires appropriate implements, such as winches, trailers and loaders (Spinelli and Magagnotti 2011b). In this respect, rubber-tired farm tractors are limited by poor off-road mobility and are only used on very favourable terrain only (Magagnotti and Spinelli 2011a). Therefore, many loggers add to their fleet one or more crawler (i.e. tracked) tractors, for coping with less favourable terrain conditions. An unpublished partial survey conducted in the Italian Alps found that 10% of the farm tractors used in forestry are tracked (92 tractors out of 888). Compared to conventional farm tractors, crawlers offer better manoeuvrability and superior traction capacity (Vaughan 1988). For these reasons they are used especially for bunching (De Lasaux et al. 2009) and skidding (Hill 1991). Unfortunately, crawlers generate a much greater site impact than any other extraction systems commonly used in Italy: a recent study shows that damage to residual trees is twice as high, and severe soil disturbance four time as high, when crawler tractors are used (Spinelli et al. 2010). Hence, the keen interest in finding a rubber-tired replacement that can offer the same advantages without the heavy environmental impact. Such replacement should have similar size, maneuverability and investment cost as the small crawlers tractors in current use. Low investment cost is crucial to selection, given the small-scale of most logging firms in the region. Crawlers could be easily replaced with conventional rubber-tired skidders, but the acquisition of these machines would require a much larger investment and a proportionally higher utilization. On the other hand, recently appeared mini-skidders may fulfill all these specifications and qualify for substitution (McElroy 2006). The goal of this study was to compare the technical and economic performance of a conventional crawler and an innovative rubber-tired mini-skidder, used under the same conditions, assumed as typical of small-scale alpine logging. The hypothesis was that the mini-skidder offered equal or superior productivity, and equal or lower extraction cost, compared to the crawler. If not, very few loggers would consider substituting the mini-skidder for their crawlers.

Materials and method

The crawler tractor selected for the test was a *FIAT 55-85*, powered by a 40 kW diesel engine and weighing 3200 kg. This model is built by the Italian manufacturer specifically for hillside agriculture, but is often converted into a crawler skidder by small-scale loggers. The specimen on test was fitted with a roll-bar, a nose guard and a mechanical forestry winch bolted to rear end. The winch had a 60 kN maximum pulling force and its single drum contained 50 m of steel cable with a diameter of 10 mm. The estimated investment cost for the complete new machine was 38000 €.

The mini-skidder was a *Hittner ECOTRAC V55*, powered by a 40 kW engine and weighing 3600 kg, hence in the same size class as the crawler. This machine is built in Croatia specifically for small-scale logging and its geometry closely resembles that of a conventional skidder (Horvat et al. 2007). The machine on test was equipped with a front blade, a rear anchor plate and a hydraulic double-drum winch installed over the rear axle. Each drum had 35 kN maximum pulling force and contained 40 m of steel cable with a diameter of 10 mm. The operator sat inside a well-protected cab, with heating and ventilation system. The machine had been rented for the test directly from the manufacturer, which quoted a purchase price for the new machine of 54000 €.

Both machines were tested on the same site, in the Regional forest of Pramosio (Table 1). The treatment was selection thinning, as prescribed by the management plan. About 150 trees were felled and processed motor-manually, with chainsaws. Stems were delimbed and cross-cut in 2.3, 4.2 and 5.2 m lengths, depending on minimum small end diameter and stem quality. The stand was served by a permanent skid trail, leading to a main landing. The average and maximum slope gradient of the trail were 11% and 29% respectively. The average and maximum slope gradients of the paths on the forest floor were 23 and 33% respectively. The loaded tractors travelled downhill on the main trail and uphill on the forest floor. The tractors rotated between loading sites, so that both machines would be tested over the same range of extraction distances, and with the same distribution of short, medium and long trips.

A time and motion study was carried out to evaluate machine productivity and to identify those variables that are most likely to affect it (Bergstrand 1991). Each skidding cycle was stop watched individually, separating productive time from delay time (Bjorheden et al. 1995). Extraction distances were determined with a hip chain. The volume of all logs in each load was determined by measuring their length and their diameter at mid-length, over bark.

Tractor rates were calculated with the method described by Miyata (1980), on an estimated annual utilization of 500 scheduled hours and a depreciation period of 15 years. The calculated operational cost of all teams was increased by 20% to account for overhead costs (Hartsough 2003).

Both direct and indirect fossil energy consumption were estimated, reflecting the same principles followed by Pellizzi (1992) in his energy analysis of Italian agriculture. The indirect consumption represented by tractor manufacturing, repair and maintenance was estimated as 30 % of the total energy consumption of the tractor (Mikkola and Ahokas 2010). Further detail on financial and energy cost calculation is shown in Table 2.

The study material consisted in 131 tractor turns (75 for the skidder and 56 for the crawler), necessary for extracting 145 m^3. Overall, the valid time study sessions lasted 45 hours, equal to 6 work days.

Results and discussion

As expected, the skidder was much faster than the crawler: its speed was between 50% and 85% higher, and this difference was statistically significant (Tab. 3). The loads dragged by the skidder were one third larger than those dragged by the crawler, and this difference also proved significant to the statistical tests. As a result of its higher speed and larger payload, the skidder offered a significantly higher productivity compared to the crawler and under the same extraction distances.

The graphs in Figure 1 represents gross productivity as a function of skidding distance for the two machines and the two teams. The skidder is substantially more productive than the crawler, and the difference increases with distance, due to its higher speed and larger payload. The productivity for Team B is between 7 and 25 % higher than for Team A. The higher travel speeds achieved by Team A cannot compensate for the larger loads assembled by Team B, but they reduce the difference between the two teams as distance increases.

The graphs in Figure 1 were used to calculate skidding cost, both in financial and energy terms (Tab. 4). Replacing the crawler with the mini-skidder accrues financial savings between 30 and 50%, depending on extraction distance. Due to the larger payload and higher speed, savings increase with distance. Energy savings are even larger, because of the compounded effect of higher productivity and lower fuel consumption, which characterize the innovative mini-skidder. The higher productivity of Team B is also reflected in a lower financial and energy cost. Cost reduction averages 15%, but ranges from 7% to 24% and decreases with distance due to the compensating effect of the higher travel speed achieved by Team A.

Figure 2 shows the relationship between skidding cost and annual use. The skidder always offers a lower extraction cost than the crawler, but the margin increases with annual use. However, the crawler is an agricultural tractor and can be used for other tasks than skidding. This may allow for a more intense annual use even when logging opportunities are limited. Hence the comparison could be done by assuming different utilization levels for the two machines. Table 5 shows the annual use of the skidder and the corresponding additional number of hours per year the crawler should work on other jobs, if it was to achieve the same unit skidding cost. This is reported in the third column. If the skidder works at least 500 hours per year, it will offer a cheaper service than the crawler, regardless of how much additional work the crawler will obtain.

The new mini-skidder offers superior productivity and lower extraction cost, compared to the crawler. That is the necessary economic condition for crawler replacement, which is already desirable in terms of site impact and labor safety. Most of the forestry-fitted crawler tractors inspected during the above-mentioned informal survey do not comply with current safety regulations (i.e. EU Directive 2008/50/CE). Upgrading to current safety standards may incur substantial cost, thus making replacement the more desirable. In fact, replacement is not just a theoretical possibility, as demonstrated by the Croatian Forest Administration, which decommissioned its substantial crawler fleet in the mid 1990s and replaced it with new skidders (Beuk et al. 2007).

The superior payload capacity of the skidder depends on its different structure, which allows for a better lifting of the log ends and an easy transfer of the vertical load component onto the rear axle (Stoilov and

Kostadinov 2009). That increases the traction capacity of the skidder, especially when negotiating uphill grades (Tomašić et al. 2009). On the contrary, the structure of the crawler does not allow for the same lift, so that only a small part of the total load weight contributes to increasing the crawler's traction capacity.

The productivity levels achieved in this study equal or exceed the productivity levels reported in previous studies for similar machines. Magagnotti and Spinelli (2011b) report a productivity of 2.3 m^3 $hour^{-1}$ and an average load of 0.8 m^3 for a forestry-fitted crawler tractor as used in this study. Zečić and Marenče (2005) indicate a productivity of 2.4 m^3 $hour^{-1}$ and an average load of 1.1 m^3 for the same Ecotrac 55V mini-skidder type used in the test, working over the same distance. However, stand type and silviculture were different, which may explain the different productivity and load size. In any case, the order of magnitude is comparable, which may support the use of our productivity figures as a general reference.

If so, one may accept as a good reference also the energy cost, which ranged from 18 to 32 MJ m^{-3} for the mini-skidder and from 45 to 111 MJ m^{-3} for the crawler. These figures are comparable with those reported by Picchio et al. (2009, 36 MJ m^{-3}) and by Magagnotti and Spinelli (2011a, 60-120 MJ m^{-3}), respectively. They are relatively low, which may be expected for intermediate mechanization (Berg 1997), especially under Alpine conditions (Valente et al. 2011). Again, one notices the superior energy efficiency of the mini-skidder: this machine is a equipped with a modern Tier III engine, which is also likely to dramatically reduce emissions (Berg and Lindholm 2005).

Conclusions

Rubber-tired mini-skidders can effectively replace forestry-fitted crawler tractors. Replacement is desirable in terms of environment protection and labor safety, and offers substantial economic benefits: it requires a moderate additional investment but allows reducing extraction cost between 30 and 50%. The prospected environmental benefits are even higher, with energy consumption and site impact being reduced 3 and 5 times, respectively. The new machine qualifies as a cost-effective new product, more environmental and energy efficient than the old it is meant to replace. Most crawlers used in forestry are now quite old, and the moment is favourable to its replacement with better machines. With the intent of promoting rural development, the European Union offers grants for the acquisition of new machinery, and low-impact technologies are generally favoured over conventional, less-efficient solutions. Hence, the importance of informing regional managers about new environmentally compatible products when drawing grant schemes, advertising the new calls and evaluating applications.

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Table 1 – *Description of the test sites*

Municipality		Cleulis - Paluzza
Province		Udine
Longitude		46°57’22.26” N
Latitude		13°01’91.21” E
Altitude	m a.s.l.	1390
Slope gradient	%	42
Trail gradient	%	10
Road density	m ha^{-1}	100
Species		Picea abies (90 %) – Abies alba (10 %)
Management		High forest
Current treatment		Thinning
Age	years	100
Removal	m^3 ha^{-1}	111
Removal	trees ha^{-1}	100
Residual density	trees ha^{-1}	203
Tree DBH	m	37
Stem Height	m	25
Stem volume	m^3	1.115

Notes: m^3 are measured over bark

Table 2 – *Costing: assumptions, cost items and total cost*

Unit		Crawler	Skidder
Power	kW	40	40
Investment	Euro	38000	54000
Resale value	Euro	7600	10800
Service life	years	15	15
Utilization	h $year^{-1}$	500	500
Interest rate	%	4	4
Fuel consumption	dm^3 h^{-1}	2.1	1.3
Depreciation	Euro $year^{-1}$	2027	2880
Interests	Euro $year^{-1}$	953	1354
Insurance	Euro $year^{-1}$	953	1354
Diesel	Euro h^{-1}	2.9	1.8
Lube	Euro h^{-1}	0.9	0.5
R&M	Euro h^{-1}	3.2	4.6
Labour	Euro h^{-1}	32.0	32.0
SubTotal	Euro h^{-1}	46.9	50.1
Overheads	Euro h^{-1}	9.4	10.0
Total rate	Euro h^{-1}	56.2	60.2
Direct energy	MJ h^{-1}	91.9	57.7
Indirect energy	MJ h^{-1}	40.4	25.4
Total energy	MJ h^{-1}	132.3	83.1

Cost in Euro (€) as on November 18, 2011. 1 € = 1.37 US$

Table 3 – *Skidding conditions, productivity and cost: summary table*

		Crawler		Skidder		Difference	
		Mean	SD	Mean	SD	p	Test
Distance on trail	m	91.1	124.5	105.7	130.6	0.5063	t-test
Distance in forest	m	29.2	21.6	32.7	24.5	0.4769	MW
Winching distance	m	10.9	5.2	16.0	6.9	<0.0001	t-test
Unloaded on trail	km h^{-1}	2.8	0.9	4.2	1.6	<0.0001	MW
Unloaded in forest	km h^{-1}	1.3	0.5	2.2	1.5	<0.0001	MW
Loaded on trail	km h^{-1}	2.0	1.2	3.7	1.7	<0.0001	MW
Loaded in forest	km h^{-1}	0.9	0.4	1.5	0.8	<0.0001	MW
Load size	n° pieces	4.2	0.9	5.6	1.8	<0.0001	t-test
Load size	m^3	0.928	0.451	1.243	0.512	0.0004	t-test
Net cycle time	min^{-1}	16.3	5.6	15.9	4.7	0.7569	t-test
Total cycle time	min^{-1}	19.3	9.7	19.3	9.2	0.9366	MW
Net productivity	m^3 h^{-1}	3.6	1.6	4.7	1.7	0.0009	t-test
Gross productivity	m^3 h^{-1}	3.2	1.6	4.1	1.6	0.0027	t-test

Notes: Net cycle and productivity exclude preparation and delay time, whereas Gross cycle and productivity includes both preparation and delay time; SD = Standard Deviation; Test r= test type, where t-test is the standard two-tailed unpaired t-test, and MW is the non-parametric Mann-Whitney test.

Table 4 *–Skidding cost as a function of distance on trail, machine type and team*

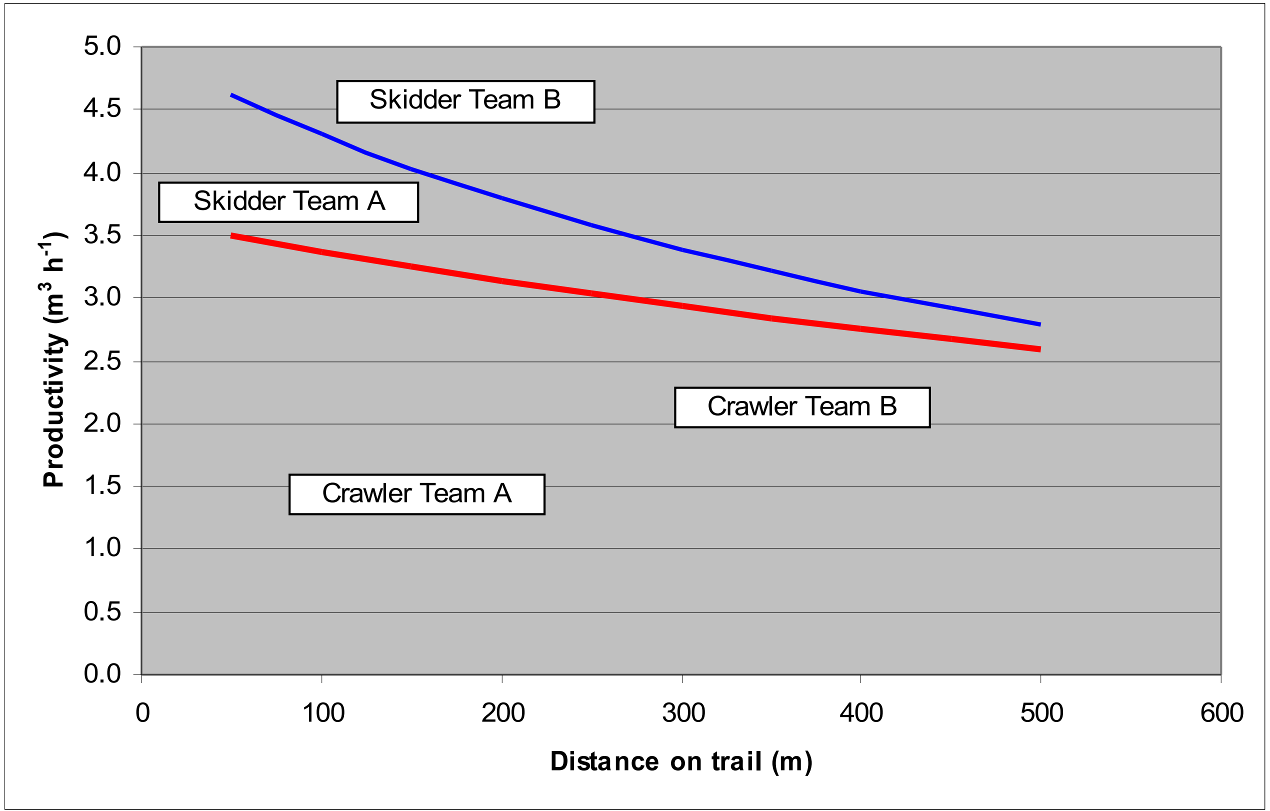
		Skidding cost Euro m^{-3}		
Dist. m	Skidder A	Skidder B	Crawler A	Crawler B
50	17.2	13.0	24.5	19.5
100	17.9	14.0	27.0	22.0
150	18.5	14.9	29.5	24.4
200	19.2	15.9	32.1	26.9
250	19.9	16.8	34.6	29.4
300	20.5	17.8	37.2	31.9
350	21.2	18.7	39.7	34.4
400	21.9	19.7	42.3	36.8
450	22.6	20.6	44.8	39.3
500	23.2	21.6	47.3	41.8
		Skidding cost MJ m^{-3}		
Dist. m	Skidder A	Skidder B	Crawler A	Crawler B
50	23.7	18.0	57.5	45.8
100	24.7	19.3	63.5	51.7
150	25.6	20.6	69.5	57.5
200	26.5	21.9	75.5	63.3
250	27.4	23.2	81.5	69.2
300	28.4	24.6	87.5	75.0
350	29.3	25.9	93.4	80.9
400	30.2	27.2	99.4	86.7
450	31.2	28.5	105.4	92.5
500	32.1	29.8	111.4	98.4

Note: Dist. = skidding distance on trail, in m; the assumed skidding distance on the forest floor is 35 m, and winching distance = 15 m, Volume figures are over bark

Table 5 –*Annual use of the skidder and additional annual hours worked by the crawler to achieve the same skidding cost*

Hours skidder	Additional hours crawler	Skidding cost € m^{-3}
100	5	33
200	50	22
300	150	18
400	300	16
500	∞	15

Figure 1 –*Gross skidding productivity as a function of distance on trail, machine type and team*



Note: the curves in the graph were calculated for a skidding distance on the forest floor = 35 m, a winching distance = 15 m, an average load size = 1.024 and 1.490 m^3 for the skidder manned by Team A and B respectively, and 0.78 and 1.217 m^3 for the crawler manned by Team A and B (mean values from the study). Productivity figures are calculated on total time consumption, and include preparation and delay time. Volume figures are over bark.

Figure 2 –*Skidding cost as a function of annual use*