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RESEARCH ARTICLE

An overview of work productivity evaluation of farm tractors in timber skidding operations

Mohammad Reza Ghaffariyan

Forest Industries Research Centre, University of the Sunshine Coast, Locked Bag 4, Maroochydore DC, Queensland

Corresponding author: Mohammad Reza Ghaffariyanv (mghaffar@usc.edu.au; ghafari901@yahoo.com)

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Abstract

Farm tractors have been applied in forest operations to carry out several tasks such as tree/felling/processing, forwarding, loading, skidding and cable yarding. Farm tractors can be equipped with special logging equipment that allows for their safe and efficient work in the harvesting of forest stands. This research is aimed to collect and review available literary sources on the productivity of farm tractors during skidding operations. The study results showed that work productivity of farm tractors for timber skidding has been studied by several researchers around the world. According to the results, the reported work productivity of skidding with farm tractors varied from 1.2 m^3/PMH_0 to 15.8 m^3/PMH_0 among international studies. Main variables impacting the work productivity of skidding included skidding distance, load volume, number of pieces per turn, tree diameter, tree length, slope of skid trails and engine power. Proper skid trail planning, applying suitable skidding equipment (e.g. winches, sulkies etc.), considering suitable engine size and proper safety standards can all help improving the work efficiency of the farm tractors during timber extracting. The information provided in this research can help the forest industry users and researchers gain proper knowledge on the work productivity of farm tractors applied for timber skidding. The study results can be also useful for planning and development purposes within small-scale forest operations.

Keywords

Farm tractor, Timber harvesting, Skidding, Productivity, Time studies, Work cycle

Introduction

Farm tractors have been in use within forest operations for many years. They have been utilized to conduct several tasks such as acting as a base machine for tree harvesting/

processing (Johansson, 1996), forwarding (Leszczyński et al. 2021; Grzywinski et al. 2018; Gilanipoor et al. 2012; Mosavi and Naghdi, 2014), winching, skidding and cable yarding (Johansson, 1996). Farm tractors can be equipped with appropriate harvesting heads to be used for tree felling and processing (Johansson, 1996; Stańczykiewicz et al. 2016). Sometimes the small trailers are attached to the farm tractors that can enable them to operate as a forwarder (Stańczykiewicz et al. 2016). The farm tractors can also be equipped with towers and winches to operate as cable yarding equipment on steep terrain.

Extracting timber from the forest to the roadside or landing is one of the main components of any harvesting systems (Conway, 1982; Uusitalo, 2010) which often is a difficult and timeconsuming task (Gülci et al. 2018). Spinelli and Baldini (1992) pointed that when farm tractors are equipped with special forestry tools (e.g., winches) they can be applied for timber extraction (Koistinen, 1991; Sennblad, 1984 cited in McCormack et al. 2000). Akay (1998) mentioned that farm tractors can be used for long log extraction when directional felling is applied, and operations are well planned (Cadorette, 1995). Skidding with farm tractors can be impacted by terrain and soil conditions, tree size and machine accessibility (Heinrich, 1987). When winches are not available, the farm tractors may be equipped with a pulley and cable to enable the extracting of whole trees when the skidding distance is less than 500 m (Cadorette, 1995). When a winch is attached to the tractors, the suggested maximum skidding distance is 200 m. Trailer and self-loader can be also attached to the farm tractors for hauling the piled logs (instead of skidding) which can increase the maximum skidding distance up to 1000 m (Cadorette, 1995 cited in Akay, 1998). Unlike dedicated forestry tractors and skidders, the farm tractors might face difficulties when operating on rough and steeper terrains (Yildiz and Altunel, 2021). Akay (2005) added that the high price of conventional forestry machines can often be unaffordable for small farm owners and harvesting contractors; therefore they prefer to apply farm tractors with lower operating costs. According to Gülci et al. (2018), modified farm tractors are widely applied in most of the European countries such as Turkey, Italy and Croatia.

As there is limited literature review available on the work productivity of farm tractors in logging operations, this article aimed to collect the published reports on this topic to provide a summary of research findings for the forestry users.

Materials and Methods

Work productivity for farm tractors in forestry

Farm tractors can be utilized as a forwarder – to haul the short logs, or as skidders – to skid the logs/small trees on the soil to the landings/roadsides. Heinimann (2021) stated that productivity studies have been applied in forestry with a major focus on labour productivity or man-machine productivity to improve work performance and enhance work design. Work productivity is defined as a ratio of some measure of out-

put to some measure of input uses (Griliches, 1998 cited in Heinimann, 2021). Mass output and time input are considered in a simple work study. Magagnotti et al. 2012 mentioned that work productivity can be impacted by different parameters including operator skills, working methods/techniques, technology type and environmental conditions. There are three methods to conduct time studies including plot level, work shift level, work cycle or elemental level (Magagnotti et al. 2012). According to Murphy (2005) time study results can be used by the forest planners for production scheduling, budgeting and comparing different procedures and equipment.

Published reports and papers in English language were found through searching in electronic databases including Google Scholar, Scopus and Web of Science Google. The following keywords were used during the search; productivity, farm tractors, timber harvesting, skidding and time studies. Forwarding, cable yarding, loading and tree felling/processing by farm tractors were not considered within this literature review. The scope of this research focused on the skidding functionality of the farm tractors in timber harvesting operations. The review results were classified into three regions including Europe, North America, and Southern Hemisphere.

Results of reviewing work productivity studies

Europe

Italy

An early study reported by Spinelli and Baldini (1992) was conducted in two types of forests including coppice and high forests. The logging arch is an A frame attached to the tractor to keep the front end of the trees/logs off the ground to reduce resistance when skidding. The arch was used to equip the farm tractors. Spinelli and Baldini (1992) believed that timber extraction using farm tractors is versatile, reliable, and cheap to fit with small scale forest operations. The coppice study included several sites covered by Turkey Oak (*Quercus cerris*) and Chestnut (*Castanea sp.*) which were clear felled by chain saw. After the trees were processed, the timber was extracted to the roadside by tractors. Slope ranged from 14% to 46%. Average stem volume ranged from 0.04 m^3 to 0.1 m^3. Skidding distance varied from 95 m to 485 m while winching distance had a range of 7 m to 20 m. There were two types of extractions including stem lengths and short logs. Tractor brands/types included Fiat 4 WD (engine power of 158 HP), Landini 4 WD (engine power of 59 HP) and Carraro 4 WD (engine power of 96 HP). The productivity of tractors varied from 1.2 m^3 per productive machine hours (m^3/PMH_0) to 8.6 m^3/PMH_0. The high forest study treatment consisted of three main species Turkey Oak (*Quercus cerris*), Beech (*Fagus sp*.) and Silver fir (*Abies Alba*). Extraction included logs and stem length. Load volume ranged from 1.2 m^3 to 2.5 m^3 while piece volume varied from 0.3 m^3 to 0.6 m^3. The skidding distances of different study plots ranged from 73 m to 1119 m. Winching distance varied from 7 m to 14 m. The average productivity varied from 4.0 m^3/PMH_0 to 5.2 m^3/PMH_0 (Table 1). Spinelli and Magagnotti (2012) stated that a standard winch and a sulky can be at-

tached to the farm tractors with a low cost to be used for part-time timber harvesting. They evaluated the productivity of wood extraction using farm tractors and sulky in central Italy. Their data were collected from seven sites under eight testing treatments. Farm tractors had engine power ranging from 64 HP to 155 HP which were equipped with the same winch (traction force of 60 kN) and the same sulky (2.2 m wide and 2 m high). Tractor model/type was not reported. Two extraction methods were applied including suspended (applied for short logs) or semi-suspended loads (applied for extracting full stems). Tree species included *Quercus cerris*, *Fagus sylvatica*, *Abies alba* and *Castania sativa*. The stands were managed as high forest or coppice. The silvicultural regimes included selection cutting, thinning and clearcut. Piece volume ranged from 0.07 m^3 to 1.0 m^3. Load size varied from 1.0 m^3 to 3.0 m^3. Depending on work conditions there were one or two operators during the tests. Skidding distance varied between 73 m to 1119 m while winching distance ranged from 7 m to 20 m. Slope of skid trails ranged from 5% to 14%. Under the above conditions the machine productivity ranged from 1.5 m^3/PMH_0 to 7.9 m^3/PMH_0 (Table 1). Working cycle included elements such as move in, load, move out and unload. The productivity predicting model included variables such as piece size, winching distance, skidding distance, engine power and number of chokermen (one or two people). Due to the difficult terrain and long distances for winching, a significant delay occurred. The loading element took the longest time (% not reported) while unloading was the quickest work element. Using sulky was more advantageous when extracting in a semi-suspension mode rather than full suspension (Spinelli and Magagnotti, 2012).

Macri et al. (2017) indicated that there are two types of small-scale harvesting systems in Italian timber extraction including farm tractors fitted with winch or grapple. In southern Italy the majority of forests are in steep terrains with the slope ranging from 20% to 60%; the suitable harvesting system can be a combination of manual felling and processing using chainsaws and timber extraction using modified farm tractors (Macri et al. 2017). Cataldo et al. (2020) carried out a study in the region of Calabria, Southern Italy, to investigate the productivity of two types of tractors operating within a cut-to-length harvesting method (felling and processing to short logs by a chain saw and extraction of short logs to landing using a tractor). Site A consisted of chestnut (*Castanea sp.*) with average slope of 30% and average tree volume of 1.1 m^3. Skidding distance averaged at 276 m. The tractor type/model was Same Silver 110 (engine power of 109 HP) which was equipped with a winch. Under study circumstances the farm tractor in site A achieved an average productivity of 2.9 m^3/PMH_0. The work cycle included elements such as travel without cargo, cable release and hooking, winching, travel loaded and unhooking. Travel loaded consumed longest time (42% of total work time) while unhooking at the landing took shortest time (8% of total work time). Variables such as winching distance, skidding distance and number of logs per turn had significant impact on working time and were used as independent variables in skidding time prediction model (regression model). Site B of the study conducted by Cataldo et al. (2020) consisted of silver fir natural stands (*Abies alba*) with an average tree volume of 1.5 m^3 which was larger than site A. Slope

averaged at 29% (close to site A). Skidding distance was 105 m which was shorter than site B. A Krpan KL2200 farm tractor (engine power of 23 HP) equipped with grapple was applied for timber extraction. This machine yielded an average productivity of 5.9 m^3/PMH_0 (Table 1) which was higher than the productivity of the tractor, equipped with a winch, operating in site A with smaller tree size, longer skidding distances and less powerful engine. The work cycle of grapple tractor included travel without cargo, grappling, travel loaded and unloading. Travel loaded consumed longest time (42% of total work time) while grappling took shortest time (2% of total work time) (Cataldo et al. 2020).

Ireland/UK

Russell and Mortimer (2005) conducted a review of small-scale harvesting systems and their application in Irish forestry. They stated that to apply the tractors in forestry, their hydraulic pump capacity should be at least 50 l/min. 3-point hitch systems allow the forestry users to set a winch for timber extraction. Purpose built farm tractors built in Nordic countries would have two function modes, including forestry and farm practices, which fits the requirements of the timber harvesting operation in Ireland. The tractor attachments suitable for timber extraction include: skidding bar and plate, skidding winch, back fork, skidding (and forwarding) grapple and back fork which can be used with different machine powers and operations as required. Wheeled logging arches can also be used to minimise the impacts of skidding on the soils. Russell and Mortimer (2005) reported that a Norwegian arch has been tested in Britain. Mini tractors made in Scandinavia are equipped with roll-over protection systems (ROPS), PTO, 3-point hitch and a towbar which makes them suitable alternatives for small scale operations. These machines can have work productivity closer to heavy tractors especially in small and diverse thinning operations. Compared to heavy tractors, the environmental impacts of mini tractors is lower and they can be equipped with skidding arches. The machine power for mini tractors can vary from small (16 HP, Vimek minimaster) to large (83 HP, Riko Mars 8.90RS) (Russell and Mortimer, 2005). Barraclough (1967) stated that the size of farm tractors is the main criterion for working in forest operations as smaller tractors have higher maneuverability in small forests. At the time of his publication (1967)Barraclough mentioned that the Massey-Ferguson FE 35 tractor was the better choice in Thetford Forest in United Kingdom (UK). The weak points of this farm tractor (such as wheel valves, radiator, stump oil strainer and stepboards) needed to be equipped with protective guards,, the track width of the wheels needed to be adjusted (to be narrower than in regular agricultural mode, to increase maneuverability), and its tyres needed to have hard walls as well as the appropriate inflation pressure, before its application in timber extraction could begin. Applications such as drawbar with chains, tongs and stackers had been attached to the farm tractors in UK for extracting timber in early 1970. Barraclough (1967) conducted some time studies on pole or log extraction with Massey-Ferguson FE 35 tractor. The work cycle was divided into elements such as travelling with no cargo, loading, travelling loaded, unloading, stacking, and adjusting. Daily output varied from 18 m^3

to 72 m^3 (assuming 6 hours effective time per day, this equals to 3 m^3/PMH_0 to 12 m^3/PMH_0) for a range of extraction distance of 10 m to 275 m.

Slovenia

Marence and Krc (2016) stated that small forest private owners use farm tractors that are modified to operate for timber harvesting. Small farm tractors are also cost-effective for small scale forestry applications. Over the recent decades more powerful farm tractors (e.g. engine power of 72 HP) have been applied (Poje, 2010). Marence and Krc (2016) used AGT 835 T tractor (engine power of 35 HP) for their study in spruce stands and equipped with specific blade and winch plus safety equipment to skid light loads uphill. In this case study the skidding distance was 190 m and the slope varied from 10% to 27%. When a tractor was used to skid load (uphill) on a section of skid trail with slope of 27%, the wheels slippage was very high that resulted in stoppage of the machine movement. This indicated the slope of 27% was the maximum slope that an AGT 835 T tractor could work with. Load size varied from 0.25 m^3 to 1 m^3. Marence and Krc (2016) analysed the tractive forces and loads in their study. They indicated that the AGT 835 T tractor would generally be suitable to skid the logs/trees when the load per turn is under 1 m^3 and the skid trail slope is less than approximately 20%. The study results confirmed that this tractor could be a useful and practical technology for occasional small scale application in forest operations in private farms and forests of Slovenia. The only small requirement is to equip this farm tractor with a small single drum winch, a rear board and a safety cabin (Marence and Krc, 2016). Work productivity of skidding was not reported in this Slovenian case study.

Turkey

A New Holland TD85D farm tractor (Figure 1) was applied to skid the logs in beech stands located within the Ordu Forest Administration area in the Black Sea region (North of Turkey) (Özturk, 2010). This machine was modified and equipped with a single drum winch. Trees were felled by a chain saw then toped to be skidded to the roadside by a farm tractor. The stand composition included species such as *Picea orientalis (L.) Link., Abies nordmanniana (Stev.) Spach., Fagus orientalis Lipsky* and *Pinus sylvestris L.* The slope varied from 25% to 45% (which basically aligned with average slope of 30% suitable for New Holland tractor). Skidding was operated uphill. Skidding distance averaged at 350 m and load size (Table 1). Log volume varied from 0.8% to 1.1 m^3 per each cycle. The study yielded a productivity of 7.7 m^3/PMH_0 at the skidding distance of 320 m. Skidding distance, load volume and number of logs per turn were significant variables in the time predicting model. Larger load volumes and longer skidding distances increased cycle time while higher number of logs per turn decreased the time consumed to skid. Skidding cycle travelling with no load, hooking up the load, winching, travelling loaded and unloading (load unhook). Travelling loaded consumed the longest time (about 35% of the total work time) while the unloading (load unhook) consumed the shortest time (3% of total work time) (Özturk, 2010).

Figure 1. New Holland TD85D farm tractor tested in Turkey (Özturk, 2010)

Turk and Gumus (2010) studied another farm tractor operating in the mixed stands of beech (*Fagus orientalis Lipsky*) and fir (*Abies bornmulleriana*) in the West Black Sea region of Turkey. Average DBH was 52 cm with a stand density of 1330 trees per ha. The silvicultural method was selective cutting where trees were selected to be felled, delimbed and processed by a chain saw operator; then the logs (length range from 1.5 m to 9 m) were skidded downhill to the landing by a farm tractor. Slope of skid trails averaged at 22% and average skidding distance was 389 m. Tractor engine power ranged from 50 HP to 89 HP with an average of 59 HP (Figure 2) but their model/type was not reported. Skidding distance, slope, engine power, number of logs per turn and volume of load per each turn were used as significant variables impacting the skidding time in regression models (Turk and Gumus, 2010). The exact value of work productivity was not included in the report written by Turk and Gumus (2010) however the authors mentioned that the average load volume per turn was 1.6 m^3 while it took 147 seconds to travel with no load (in average) and 198 seconds to travel loaded (in average) during the time study. Skid trail planning is another factor that can impact the overall productivity of tractors. Gumus and Turk (2016) developed a direct skid trail pattern in the Western Black Sea province of Duzce (Turkey) in a mixed stand of *Fagus orientalis* and *Abies nordmaniana* subsp. *Brnmuelleriana*. The stand was clear felled. Trees were felled, delimbed and bucked to short logs by a chain saw operator then the logs were extracted to the roadside. The slope ranged from 0 to 33% (load volume, log volume and tractor model were not reported). Their pattern reduced skid trail density from 281 m/ha to 187 m/ha. New direct skid trail pattern helped to reduce the length of skid trail. Gumus and Turk (2016) reported that

Figure 2. Log skidding by a farm tractor Duzce, Turkey (Turk and Gumus, 2010)

their new approach increased productivity by 16.8% (from 9.8 m^3/PMH_0 (at skidding distance of 250 m) to 15.8 m^3/PMH_0 (at skidding distance of 100 m)).

The other study was conducted by Gülci et al. 2018 in black pine stands (*Pinus nigra*) in the Southwest of Turkey. Trees were felled by a chainsaw operator and bucked to short logs to be extracted to the roadside using a Türk Fiat 450 farm tractor (engine power of 48 HP). In addition to the tractor operator there was another worker who set the chokers to the logs when loading and released the chokers when unloading at the landing (choker setter). The study included two treatments with average slopes of 20% and 30% for uphill skidding. Mean load volume was 0.56 m^3 for sites with slope of 20%, while for the other site (slope of 30%) – the load volume averaged 0.55 m^3. For the same skidding distance of 100 m the average skidding productivity was 5.72 m^3/PMH_0 and 4.30 m^3/PMH_0 for the two slope classes. Travelling loaded and travelingl without a load took the largest share of the total working time. When a tractor worked on a slope of 30%, its travel loaded time increased by 47% compared with working on a gentle slope of 20%.

Özturk et al. (2019) conducted another trial in Northwest Turkey in a stand of *Pinus nigra*. The terrain was rough. Trees were felled, delimbed and bucked to short logs by a chain saw operator. A Fiat 54C farm tractor (engine power of 55 HP) was applied to extract the logs using short chains (and chokers) attached to the back of the tractor. Slope of skid trails averaged at 4% while skidding distance averaged at 385 m. The average load volume was 1.8 m^3 (with an average of 2 pieces per each work cycle). Under the above operational conditions, the Fiat 54C tractor yielded an average productivity of 4.7 m^3/PMH_0. Skidding distance and load volume were significant factors impacting the productivity of the tractor. However, number of logs per turn was not

a significant factor in this case study. Cycle time included working elements such as travel without a load, hooking, travel loaded and unhooking in which travel loaded took the longest time and unhooking was the shortest element.

A Tumason farm tractor (power of 75 HP) equipped with a winch was studied by Gülci (2020) in the Eastern Mediterranean region of Turkey. The stand composed of black pine (*Pinus nigra Arn.*), Turkish red pine (*Pinus brutia Ten.*), fir (*Abies cilicica*) and cedars (*Cedrus libani* L.). During winching, the ground slope ranged from 45% to 50% and the slope of the skid trail varied from 5% to 10%. Trees were felled and then winched uphill to the tractor. Then whole trees were skidded backward to the roadside to be processed into short logs. The average tree volume was 0.64 m^3. Skidding distance and winching distance averaged at 90 m and 31 m respectively. The average winching productivity was 13 m^3/PMH_0 while the extraction phase productivity (excluding winching) averaged at 14.3 m^3/PMH_0. Among the various work elements in the winching phase the winching process (pulling the trees to the tractor by a winch) took the longest time (49% of total winching time) but traveling loaded back to the landing consumed the longest time (64% of total skidding time) among the other components of the working cycle. Skidding distance, load volume, tree diameter and tree length were found as significant variables impacting the work productivity of the winch and tractor (Gülci, 2020).

America

USA

According to PennState Extension's report on "tractors in the wood' the farm tractors are applied in farms and rural areas to do different tasks such as timber harvesting, fencing, tree felling and extraction of firewood in the USA (https://extension.psu.edu/tractors-in-the-woods). Applying farm tractors by inexperienced operators who are not familiar with the required safety standards of timber harvesting operations can result in high risks of injury or fatalities. The farm tractors are not fully equipped with standard forestry Roll Over Protection Systems (ROPS) and Fall Over Protection Systems (FOPS) thus their usage should be limited to firewood harvesting or stationary functions. PennState Extension suggested the following technological options to improve safety and efficiency of skidding operations; 1) using an arch (Figure 3) or a sulky which could assist with lifting the end of a log, 2) attaching a 3-point mounted grapple or 3-point mounted winches (Figure 4).

Farm tractors have been well applied as base machines in small scale harvesting operations in the USA due to the following advantages that they bring: less capital investment requirements; possibility of a combination with different equipment to provide multi-function capabilities, small physical size, low ground pressure (Wilhoit and Rummer, 1999). Farm tractors equipped with a grapple are suitable machines for thinning pine plantations with small tree sizes and they can be also well-matched with mechanized felling/bunching to improve work productivity in tree length harvesting method (Wilhoit and Rummer, 1999). The productivity of farm tractors with grapple might be slightly higher than that of tractors equipped with a trailer (forwarder) (Blonsky, 1971 cited in Wilhoit and Rummer, 1999). When farm tractors equipped

Figure 3. A log arch applied for skidding in USA (https://extension.psu.edu/tractors-in-thewoods)

Figure 4. 3-point mounted grapple and winch in USA (https://extension.psu.edu/tractors-inthe-woods)

with winches (Figure 5) are used in combination with manual felling operations, then they might become labour intensive as extra workers would be required to help with rigging, hooking, and unhooking (LeDoux, 2011). LeDoux (2011) emphasized that farm tractors can operate safely on gentle terrain (Figure 5) but their application on steep or very steep terrains would not be safe or practical.

Southern Hemisphere

Australia

McCormack et al. (2000) mentioned that most forest operations in Australia are carried out by industrial-scale operations such as the combination of harvesters and forwarders (Ghaffariyan et al. 2019) or feller-bunchers and skidders (Ghaffariyan and

Figure 5. Large farm tractor with winch tested in USA (LeDoux, 2011)

Brown, 2013; Ghaffariyan, 2020). McCormack et al. (2000) suggested that small-scale harvesting is still on its early stage of development in Australia, and it needs to develop further especially for producing considerable amounts of timber from the farm plantations. Farm tractors could be suitable for farm forestry within the cut-to-length method (a tractor equipped with a trailer) or tree length/long wood methods (a tractor equipped with a winch). McCormack et al. (2000) reported that the farm tractors were applied in one of their harvesting case studies in South East Victoria. A pine plantation (*Pinus radiata*) aged from 1 to 40 years was established on grounds with average slope of 45%. Trees were felled and processed by chainsaw to produce pulpwood in thinning operations. The logs were then skidded to the roadside using a Ferguson 399 4WD farm tractor (engine power of 100 HP). The accumulated logs were then forwarded by a Fiat 6066 4WD farm tractor equipped with a trailer (including a self-loading crane) to a central yard to be transported by trucks to the end-user. The farmer operated all stages of the harvesting operations as he owned all of the above mentioned equipment (McCormack et al. 2000). Work productivity of the farm tractor was not reported in this case study. McCormack et al. (2000) mentioned that harvesting operations were mostly conducted by family members (55% of the cases) and harvest contactors (30% of the cases).

Chile

A case study was conducted by Carey et al. (2018) in the Las Palmas area in Chile. The stands included plantations of *Eucalyptus globulus* mixed with natural stands of *Acacia melanoxylon*. The average tree volume was 0.1 m^3. The average ground slope was 16%. A whole tree harvesting method was applied within a semi-mechanised

Figure 6. Small farm tractor with grapple tested in Chile (Carey et al. 2018)

system for biomass recovery in the study area. Felling was performed using two operators with chainsaws who stacked the small trees into bundles. The whole trees (in bundle form) were then skidded to the roadside using a John Deere 6403 farm tractor equipped with a grapple (Figure 6).

Skidding cycle included travelling without a load, loading, travelling loaded and unloading. Work variables measured in the time study included travel distance, slope of skid trail and number of trees per turn. The regression analysis demonstrated that the skidding distance and number of trees per turn were the only variables that significantly impacted the work productivity. The slope did not have a significant impact as it ranged only from 0% to 20%. The skidding distance varied from 40 m to 180 m and corresponding work productivity varied from 2.8 to 5.9 Green tonnes per PMH_0 (assuming a factor of 1:1 conversion this can be reported as m^3/PMH_0 to be consistent with other studies presented in Table 1) in skidding with farm tractor. The utilisation rate during the study was 72.7%. Delays included personal delays(11.2%) and operational delays (15.6%) and mechanical delays (0.3%). Major operational delays occurred due to the waiting time for pilling the trees into bundles and the extra waiting time for load adjustments and securing by the crew. Table 1 presents a summary of selected productivity studies on farm tractors used for timber skidding in different regions.

Conclusions

Main variables impacting the productivity of farm tractors (when used for skidding operations) include: skidding distance, load volume, number of pieces per turn, tree diameter, tree length, slope of skid trails and engine power (Gülci, 2020; Cataldo et al. 2020; Özturk, 2019; Gülci et al. 2018; Carey et al. 2018; Spinelli and Baldini, 1992;). Farm tractors equipped with a winch (e.g. a single drum winch) can be suitable for

Table 1. Summary of selected productivity studies on farm tractors

Continent/ country	Tractor model	Power (HP)	Skidding distance (m)	Slope (%)	Load volume (m^3)	Piece volume (m^3)	Average productivity (m^3/PMH_0)	Reference
Europe Italy	Fiat 4 WD, Landini 4 WD and Carraro 4 WD	59158 59158	95-485 73-1119	14-46 14-46	0.6-3.0 1.2-2.5	0.04-0.1 0.3-0.6	1.2-8.6 4-5.2	Spinelli and Baldini (1992)
Italy	n/a	64-155	73-1119	5-14	1.0-3.0	0.07-1.0	1.5-7.9	Spinelli and Magagnotti (2012)
Italy	Husqvarna Silver 110 Krpan KL2200	23 88	276 105	30 29	- -	1.1 1.5	2.9 5.9	Cataldo et al. (2020)
Turkey	New Holland TD85D	85	140-320	25-45	1.6-2.1	0.8-1.1	7.7-11.3	Özturk, 2010
Turkey	Türk Fiat 450	48 48	100 100	20 30	5.4 5.2	0.56 0.55	5.7 4.3	Gülci et al. 2018
Turkey	Fiat 54C	55	385	4	1.8	0.9	4.7	Özturk et al. 2019
Turkey	Tumason	75	90	5-10	-	0.6	14.3	Gülci, 2020
Southern Hemisphere Chile	John Deere 6403	102	40-90	16	–	0.1	2.8- 5.9	Carey et al. 2018

small scale forest operations in steep terrains (Gülci, 2020). As Özturk et al. (2019) suggested, planning shorter skid trails can reduce the skidding time and costs for the farm tractors. To minimise the soil compaction and disturbance, the skidding operation should be conducted in dry soils. If timber is skidded under wet soil conditions, then it should stop when machine traffic starts making deep ruts on the soil (Macri et al. 2017). More logging residues can be left on the topsoil of skid trails to reduce soil compaction (Macri et al. 2017). Cataldo et al. (2020) concluded that a grapple tractor might be more convenient than winch tractors in similar operating conditions due to the shorter time required for loading and unloading. Farm tractors can play a major role in small scale forestry in Mediterranean forests. Spinelli and Baldini (1992) recommended using a logging arch with tractors to facilitate faster travelling, safer operation and lower soil damages. When tractors are required to work in both coppice and high forests, then it is recommended to apply more powerful machines (engine power larger than 80 HP) (Spinelli and Baldini, 1992). Spinelli and Magangotti (2012) concluded that the application of a winch and a sulky can increase the work productivity of farm tractors, enabling them to skid large loads between 1 m^3 to 5 m^3. However, there is a need to improve the design and quality standards of current sulkies and to reduce the purchase price, upscaling the production by larger manufacturers in Italy (and Central Europe). Spinelli et al. (2016) indicated that coppice forest

operations in Europe are still based on low mechanized systems where farm tractors are one of the cheap and versatile extraction alternatives to apply. Carey et al. (2018) concluded that based on their observations on comparing the farm tractors with oxen for biomass skidding, the farm tractors, due to their large size, showed less flexibility and manoeuvrability than oxen when operating in small spaces. The other issue was the limited ability of the grapple when picking up small biomass trees. These technical limitations can be considered by the forest harvesting planners when planning the operations and by forest technology providers to improve the design and capabilities of the farm tractors applied in timber harvesting.

There are some planning options that can help improve work productivity of timber extraction with farm tractors such as directional felling, well-planned skid trails prior to extraction (Gülci et al. 2018, Gumus and Turk (2016), Barraclough (1967)). The experience gained by McCormack et al. (2000) in Australia indicated that combination of steep terrains and poor access would make it necessary to plan proper and special access roads and skid trails on the farms. Such a plan can facilitate a safe and productive harvesting operation.

The ergonomic conditions of farm tractors (e.g. work position, cabin size, noise level, operator seat etc.) should meet the standards of the forestry conventional skidders (and in general – timber harvesting machines) which was the case for Swedish farm tractors tested by Johansson (1996). Note that the Türk Fiat 450 Fiat and 54C farm tractors studied in Turkey (Özturk et al. 2019; Gülci et al. 2018) were not equipped with a safe cabin to provide the required safety to the operators against rolling over or falling objects. ROPS and FOPS should be considered when applying the farm tractors to protect both operator and machine (Wilhoit and Rummer, 1999). Any heavy forestry applications including log loading, skidding or pushing should be carried out by specialised logging machines. Adjusting farm tractors for forestry operations can be technically possible but economically it might become an expensive option (https://extension.psu.edu/tractors-in-the-woods; Wilhoit and Rummer, 1999). Thus, the farm tractors can be limited to perform lighter harvesting tasks (Marence and Krc, 2016).

Spinelli and Magagnotti (2012) suggested conducting further studies on the application of farm tractors equipped with a sulky to enable the comparison of work productivity rates under different operational and environmental conditions and develop a general model to predict and benchmark the gained productivities.

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