International Journal of u-and e-Service, Science and Technology
Vol.7, No.4 (2014), pp.375-384
http://dx.doi.org/10.14257/ijunnesst.2014.7.4.34

Study on Effect of Multifunction Wheeled Skidder on the Physical and Chemical Properties of Trail Soil

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Abstract

Based on lots of survey and testing, the effect of multifunction wheeled skidder on the physical and chemical properties of trail soil of artificial mixed broadleaf-conifer forest was analyzed quantitatively. The results show that the bulk density of soil increases, the property of keeping water of soil decline, the porosity of soil decreases; the value of soil PH and organic matter. For the nutrient elements, the quantity of nitrogen and potassium increase, and the quantity of phosphorus decrease. The effect of multifunction wheeled skidder on the physical and chemical properties of soil is small when compared to J-50 tractor. The results of study can be used for correctly selecting skidding operation, operation equipment, and reducing the effect of skidding operations on forest soil. At the last, based on the ecological harvesting operation, the corresponding technologies of reducing the damage of soil for timber skidding were put forward.

Keywords: *multifunction skidder; skidding operation; skidding road; physical and chemical properties of soil*

1. Introduction

Forest soil is an important part of forest ecology. It is the material basis on which forests rely for existence. To maintain and improve the fertility of forest soil has become a key point for the system stability of forest ecology and the sustainable development of forestry. Skidding operation has the greatest impact on soil. How to reduce the damage to forest soil during skidding operation has become one of the important topics of ecological forest harvesting operation [1-2]. The animal skidding operations labor costs increased year by year, and it also has the shortcomings of low resource utilization rate, low bucking percentage and low skidding efficiency. The animal skidding operation has gradually become unsuitable for the actual situation of timber production in the Northeast Forest Region. Therefore, machinery skidding should be adopted to replace the animal skidding [3]. However, because the forest harvesting operation has the new features of scattered operation places, big gradient, sparse trees, low skidding quantity per hectare and low timber output per standing tree, and it is not suitable to adopt the existing large skidding tractors exclusively used for the forestry such as J-50 and J-80, so the new, small, flexible and environment-friendly multifunctional skidding machines which are more suitable for the timber production reality are needed to be explored.

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ISSN: 2005-4246 IJUNNEST

The principal parameters for the ecological multifunctional wheeled skidding tractor with high efficiency and low consumption were selected and determined according to the actual survey on Daxi Forest Farm of Linjiang Forestry Bureau of Jilin Forest Industry Group. Based on the principal parameters, the reconstruction design for ZLY925D loader developed by the Shandong Shiliyuan Engineering Machinery Co., Ltd. was carried out, and the winch and carrying board were added to the loader, and the winch and carrying board and the sample tractor were linked together at last. After the design and reconstruction of the sample machine was completed, the skidding test was carried out in Linjiang Forestry Bureau of Jilin Province. This multifunctional skidder combines timber winching, loading, unloading, obstacle clearing, road repairing, and rollover warning functions together. This paper focuses on researching the impact of the designed multifunctional wheeled skidding tractor on the physical and chemical properties of soil in artificial forest. The testing results will be used to compare with other skidding operation mode (J-50 skidding tractor), and thus verifies the designed multifunctional wheeled skidder is environment-friendly in the skidding operation in the Northeast Forest Region. Meanwhile it has great significance in realizing the sustainable management and utilization of forests and promoting the forestry equipment industry of our country to rise from the valley bottom.

2. Site Conditions

The sample plot for test is in Daxi Forest Farm, Linjiang Forestry Bureau, Jilin Forest Industry Group. The region has the monsoon climate of temperate zone. It is dry, cold and snowy in winter; it is warm and rainy in summer. The mean annual precipitation is 660mm. The mean annual temperature is 1.3℃. The frost-free period is about 115 days. The skidding operation field is in Small Team 1, Forest Team 58, Daxi Forest Farm. The designed area is 10.9hm^2. The height above sea level is 670m. The exposure is southwest with the average gradient of 6-8°. The soil is dark brown forest soil with the average soil thickness of 20cm. The soil is moist. The vegetation type is scouring rush with the middle cover degree. The boscage type is acer ukurunduense with the dense cover degree. The sample plot is the artificial forest. The forest type is the mixed broadleaf-conifer forest. The principal species include larches, Korean pines, Northeast China ashes and lindens. The average age of strands is 48a, the average DBH is 24cm, the average height is 18m, the canopy density is 0.9, and the timber reserves are 244m3/hm^2. The felling method is selective felling operation. The developed multifunctional wheeled skidding tractor was used to carry out the tree-length skidding operation in the test place in December 2012.

3. Methods

3.1. Soil Sampling

As According to the actual situation of the sample plot for test, the measurement of physical and chemical properties of soil was carried out, taking 3 pieces of land with the area of 20m×20m respectively in the primary skid trail, 3 secondary skid trails and the forest land near the skid trail as the comparing sample plots in September 2012. The specific settings of sample plots and sampling points are as shown in Figure 1. Z represents the primary skid trail (setting up 4 different positions of Z1, Z2, Z3 and Z4 according to the passing times of tractor in descending order), and C represents the secondary skid trail (3 different positions of C1, C2 and C3), and Ck represents the reference sample plot (15 reference points of Ck1-Ck15). 5 measuring points were set up in each sampling point on the primary and secondary skid trails.

The specific positions of measuring points are on the tracks of two wheels, between the tracks and on both sides of the tracks. The test took 5 data from each sampling point, and then calculated the average. Based on the current research on the impact of skidding operation on physical and chemical properties of forest soil, the impact on the properties of soil on the surface of forest land is the greatest [1,4]. Therefore, only the topsoil (0-10cm) was collected in this study. The cutting-ring method was used to collect topsoil from each measuring point. The soil was put into plastic bags with written labels, and then taken back to the laboratory for test.

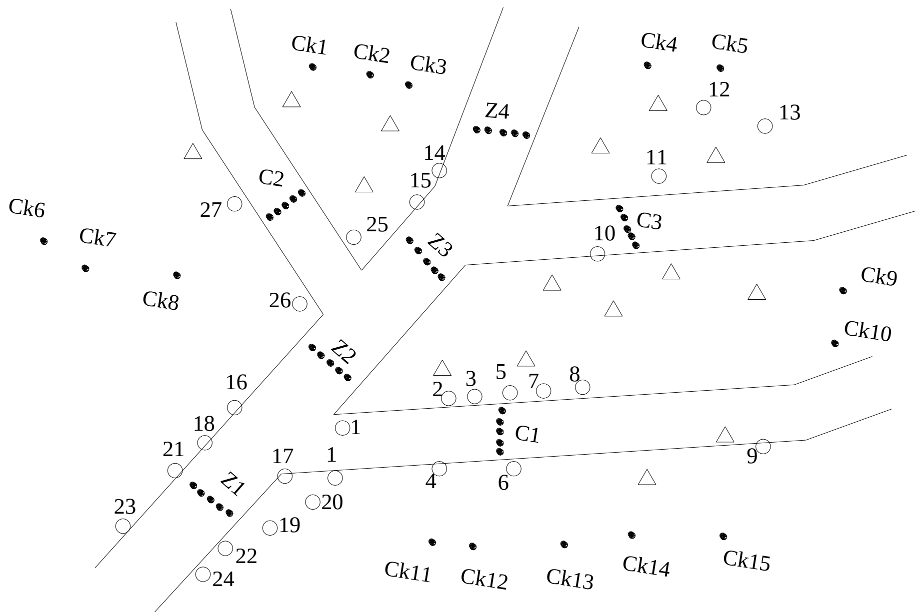

Figure 1. Distribution of Soil Physical and Chemical Prosperities Measurement Sampling Points

Notes: ○ Damaged Remained Trees, △Felled Trees, • Sampling Points

3.2. Measurement of Soil Physical and Chemical Properties

3.2.1. Soil Moisture-Physical Properties

Soil moisture – physical properties measurement used the cutting-ring method (LY/T 1215-1999).

3.2.2. Chemical Properties of Soil

①The PH value was measured with the acidity meter (LY/T 1239-1999), using the water immersion method with the water and soil volume ratio of 50:1; ②the soil organic matter was measured with the oil-bath potassium dichromate oxidation method (LY/T 1237-1999); ③the total nitrogen was measured with the automatic Kjeldahl method (LY/T 1228-1997), using VS-KT-P full-automatic nitrogeter; ④the hydrolytic nitrogen was measured with the diffusion method (LY/T 1231-1999); ⑤the total phosphorus was measured with the acid soluble molybdenum antimony colorimetric method (LY/T 1232-1999); ⑥the available phosphorus was measured with molybdenum antimony colorimetric method (LY/T 1233-1999); ⑦the total potassium was measured with the flame photometry (LY/T 1234-1999); ⑧ the rapidly available potassium was measured with the flame photometry (LY/T 1236-1999).

4. Results and Analysis

4.1. Analysis of Soil Physical Prosperities

The investigation items about the soil moisture–physical prosperities in this study include the volume weight of soil, the maximum water-holding capacity, the capillary moisture capacity, the non-capillary porosity, the capillary porosity and the total porosity. The investigation results are shown in Table 1.

Table 1. Results of Soil Moisture-Physical Properties

		Water-holding capacity (Volume fraction)%		Porosity (Volume fraction) %		
Soil type	Volume weight of soil (g/cm^3)	Maximum water-holding capacity	Capillary moisture capacity	Non-capillary porosity	Capillary porosity	Total porosity
Ck	0.98	40.37	38.47	5.89	36.26	42.15
C1	1.07	38.66	32.70	4.47	33.64	38.10
C2	1.02	40.20	36.76	4.56	35.94	40.51
C3	1.10	35.59	33.32	4.34	34.73	39.07
C-Ave.	1.06	38.15	34.26	4.46	34.77	39.23
Z1	1.18	36.92	30.61	4.33	30.66	34.99
Z2	1.15	35.54	29.88	4.29	32.30	36.60
Z3	1.13	36.59	30.48	4.29	33.69	37.98
Z4	1.07	39.12	35.91	4.37	34.79	39.16
Z-Ave.	1.13	37.04	31.72	4.32	32.86	37.18

4.1.1. Soil Volume Weight

The soil volume weight refers to the mass of dry soil in the unit volume of original-state soil. It can comprehensively reflect soil structure, tightness, porosity, and biological activities in soil and it can also affect the release and settlement of nutrient elements in soil aggregate. In the process of skidding operation, the physical properties of forest land changed correspondingly since the original environment of forest land was disturbed and damaged. From Table 1, we can find that the soil volume weight on the primary skid trail and the secondary skid trail changed obviously in comparison with the reference sample plot. The soil volume weight increased in average from 0.98 of the comparing land to 1.06 and 1.13 with the increasing rate of 8.5% and 15.53%, respectively. Compared with the secondary skid trail, the primary skidding trail changed more obviously. The sampling point Z1 was especially obvious because all the skidding operations went through it, and the soil of this sampling point was grinded repeatedly. As shown in Table 1, as the times of tractor skidding operation increased (Z4 to Z1), the soil volume weight also increased gradually. This shows that the soil volume weight on skid trails was on the rise as the times of vehicles going through skid trials increased.

4.1.2. Soil water-Holding Capacity

The soil water-holding capacity refers to the indicator about the water content that soil can absorb and hold. Specifically, it includes the maximum water-holding capacity, the capillary water-holding capacity and the field water-holding capacity. Only the first two indicators were studied in this paper. The skidding operation had obvious impact on the soil water-holding capacity on skid trails because the topsoil on skid trails was removed and the tractor and timbers impacted and compressed the soil. As showed in Table 1, in comparison with the reference sample plot, the maximum soil water-holding capacity on the primary skid trail and the secondary skid trails decreased by 0.08 and 0.05 in average with the decreasing rate of 8.25% and 5.5%, respectively. Similar with the change of maximum water-holding capacity, the capillary water-holding capacity also showed the downward trend with the decreasing rate of 17.54% and 10.94%, respectively. Compared with the primary and secondary skid trails, the topsoil water-holding capacity on the primary skid trails decreased more. The test data also shows that the general trend of soil water-holding capacity was downward as the passing times of vehicles increased (Z4 to Z1). This illustrates that the maximum topsoil water-holding capacity and the capillary water-holding capacity on skid trails decreased as the passing times of vehicles increased.

4.1.3. Soil Porosity

The soil porosity is the percentage of soil pore space in the total volume of soil. It is an important parameter which can affect the movement of moisture and gas. It determines the root system of trees and the activities of soil organisms. The skidding operation had compaction effects on the soil structure, and directly caused the change of soil pore space. Thus, the total porosity, the capillary porosity and the non-capillary porosity of soil on the primary skid trail and the secondary skid trail were lower than those of the comparing forest land. As shown in Table 1, the decrease of the non-capillary porosity on the primary skid trail and the secondary skid trail was 26.64% and 24.34%, respectively; the decrease of the capillary porosity on the primary skid trail and the secondary skid trail was 6.81% and 1.39%, respectively; the decrease of the total porosity on the primary skid trail and the secondary skid trail was 11.79% and 6.94%, respectively. From the changes of the three kinds of porosity, the decrease of the non-capillary porosity was the most obvious, and the decrease on the primary skid trail was greater than that on the secondary skid trail. From the analysis on the data of Z1 to Z4, the porosity of soil showed the downward trend as the times of tractors passing through forest land increased.

The soil has good structure when big and small pores exist in the soil at the same time. When the total porosity is 50-60%, the air permeability, the water permeability and the water-holding capacity are coordinating [5]. As shown in Table 1, the total porosity of topsoil on the forest land (comparing land) in the experimental plot (42.15%) was close to the lower limit (50%) of total porosity of soil with good structure. It shows that the soil type has a good structure. After the tractor skidding operation, the total porosity of topsoil on skid trails lowered with varying degrees. This illustrates that the good soil structure was damaged to some degree, but the damage to the soil structure was not very serious according to the decrease of data.

4.2. Analysis of Soil Chemical Prosperities

In the process of trees growing, they need to absorb different nutrient substances from soil continually, including organic matter, nitrogen, phosphorus, potassium and other nutrient element and some microelements. The growth of trees also needs suitable PH of soil. The skidding operation inevitably has some effects on the chemical properties of soil while changing the physical properties of soil. The investigation items about the chemical properties of soil include the PH of soil, the organic matter, the total nitrogen, the total phosphorus, the total potassium, the hydrolysable nitrogen, the available phosphorus, and the rapidly available potassium. The investigation results are shown in Table 2.

Table 2. Results of Soil Moisture-Physical Properties

Soil type	PH (H_2O)	Organic matter (g/kg)	Total nitrogen (g/kg)	Total phosphorus (g/kg)	Total potassium (g/kg)	Hydrolysable nitrogen (mg/kg)	Available phosphorus (mg/kg)	Rapidly available potassium (mg/kg)
Ck	5.33	25.60	6.00	1.63	18.84	583.73	5.98	14.16
C1	5.69	19.28	6.10	1.52	20.98	595.07	8.80	16.00
C2	5.47	27.55	5.94	1.56	16.32	617.90	3.66	10.36
C3	5.34	26.83	5.98	1.85	19.81	688.63	6.54	20.15
C-Ave.	5.50	24.56	6.01	1.64	19.04	633.87	6.33	15.51
Z1	5.68	21.31	7.22	1.84	17.20	620.02	3.81	10.11
Z2	5.60	22.83	6.12	1.93	16.63	699.80	5.32	16.02
Z3	5.53	23.46	6.33	2.16	20.10	628.41	6.25	19.84
Z4	5.53	21.54	5.64	1.85	22.67	632.79	6.74	18.77
Z-Ave.	5.59	22.29	6.33	1.94	19.15	645.25	5.53	16.19

4.2.1. Soil PH

The reaction of soil water solution is referred to as potential of hydrogen (PH) of soil. The soil PH directly influences the sprouting of tree seeds, the growth of seedlings, the organisms in soil and the bio-chemical process. The impact of skidding operation on the soil PH value on skid trails is shown in Table 2. From Table 2, the topsoil PH value on skid trail was slightly greater than that of the reference sample plot. The primary skid trail had greater change than the secondary skid trail. As for the sampling points of Z1 and Z2 which were compacted repeatedly, the change of PH value was more obvious. The average values of PH on the primary skid trail and the secondary skid trail increased by 0.05 and 0.03 with the increasing rate of 4.9% and 3.28%, respectively. The reason was that the skidding operation almost removed all the ground covers on topsoil of skid trails. The fallen leaves of mixed broadleaf-conifer forest, the source of acidic materials, were reduced; the organic acid produced by the decomposition of fallen leaves was reduced. Thus, the acidity of soil layer on skid trails was weakened. Meanwhile, the removal of dry branches and fallen leaves on skid trails made the topsoil directly expose to the external environment, the temperature of soil become higher than that of soil on sample plot and the activities of microorganisms in soil become more active. In addition, the eluviation of rainfall also made the acidification of soil increase.

4.2.2. Soil Organic Matter

The soil organic matter is the general term for different products and synthetic products produced by all the animal and plant residues formed in soil and added into soil in different decomposition phases. It has great significance to soil forming, soil fertility, environmental protection, and sustainable development of forest. From Table 2, in comparison with the reference sample plot, the soil organic matter on the primary and secondary skid trails decreased by 0.13 and 0.14 respectively with the decreasing rate of 12.96% and 4.09%, respectively. Compared with the soil on the secondary skid trail, the quantity of soil organic matter on the primary skid trail became smaller. Except for the sampling point of Z4, as the passing times of tractor increased, the quantity of organic matter became smaller and smaller. The reason was that the skidding operation made the topsoil be washed by rain water and made the organic matter of soil run off in large quantity. The reduction of organic matter would change the formation of soil structure, the soil fertility and the water-holding capacity of soil. Therefore, some measures should be taken to prevent the soil organic matter from running off when carrying out skidding operation.

4.2.3. Nutrient Elements in Soil

(1) Change of Nitrogen: After skidding operation, the quantity of total nitrogen and hydrolysable nitrogen in the topsoil of the primary and secondary skid trails increased in comparison with those of the reference sample plot. The increase of total nitrogen was 0.1% and 5.42% respectively, and the increase of hydrolysable nitrogen was 10.54% and 8.59% respectively.

(2) Change of Phosphorus: The quantity of total phosphorus and available phosphorus in the topsoil of the primary and secondary skid trails decreased in comparison with those of the reference sample plot. The quantity of total phosphorus in the topsoil on the primary and secondary skid trails decreased by 0.19 and 0.01 respectively, and the decreasing rate was 19.25% and 0.75%, respectively. The quantity of available phosphorus in the topsoil of the primary and secondary skid trails decreased with the rate of 7.53% and 5.28%, respectively.

(3) Change of Potassium: Similar with the change of nitrogen, the contents of total potassium and available potassium increased. The increase of the quantity of total potassium was 1.65% and 1.05% respectively, and the increase of the quantity of available potassium was 14.33% and 9.52%, respectively.

From the change of nutrient elements, the quantity increase of nitrogen and potassium might be caused by the following reason. The reduction of trees on skid trails after skidding operation made the solar radiation directly reach the topsoil on skid trails, the temperature of air and soil was higher than that on the reference sample plot, and the mineralization of mineral substances in soil was strengthened. In addition, the skidding trails for this skidding operation was newly opened up, and the disturbance on soil after skidding period also accelerated the transformation of nutrient elements in soil, thus some nutrient elements were increased. Except the quantity of phosphorus in the topsoil on the primary skid trail decreased obviously, the phosphorus in other places changed slightly. This might because the iron in soil fixed the phosphorus and weakened the activity of phosphorus. Of course, the change of nutrient elements in the topsoil after skidding operation also related to the time of data collection. As the time went by, the quantity of different element in soil also had different changes. From the general average value, the change in the quantity of nutrient elements in the topsoil on the primary skid trail was greater than that on the secondary skid trail, but the relationship between the change in the quantity of nutrient elements and the passing times of tractor was not very obvious.

5. Conclusions and Suggestions

This paper mainly discussed the impact of multifunctional wheeled skidding tractor on the physical and chemical properties of the topsoil on skid trails after skidding operation. With the combination of the pressure and vibration that the tractor, the collected timbers and the dragged timber bundles produced on skid trails, the physical and chemical properties of the topsoil on skid trails changed. (1) The tractor skidding operation had some impact on the soil physical and chemical properties on skid trails. The soil volume weight was higher than that of the reference sample plot. The maximum water-holding capacity, the capillary water-holding capacity, the non-capillary water-holding capacity, the capillary porosity and the total porosity were lower than those of the reference sample plot. The impact on the primary skid trail was greater than that on the secondary skid trail. The reason was that the repeat movement and compaction of timbers and machines disturbed the soil and reduced the volume weight and porosity of soil. (2) The tractor skidding operation also had impact on the topsoil chemical properties on skid trails. The topsoil PH value on skid trails was slightly bigger than that of the reference sample plot. Some soil organic matters ran off. The quantity of nitrogen, potassium and other nutrient elements also increased slightly in comparison with the reference sample plot. The quantity of phosphorus decreased, but the decrease was not very obvious.

In order to analyze the impact of the environment-friendly multifunctional skidding tractor on the forest soil during skidding operation more objectively and more scientifically, the comparative analysis should be done with the skidding operation of J-50 skidding tractor used by the forest area at present. Therefore, the forest harvesting operation and the forest soil similar to those of this test were selected to make the comparative analysis [6]. According to the research results, after the skidding operation of J-50 tractor on the primary skid trail and the secondary skid trail, the increase of the soil volume weight was 104.3% and 93.5%, respectively, and the decrease of the soil maximum water-holding capacity was 57.9% and 57.2%, respectively, and the decrease of the total capillary porosity was 14.4% and 16.5%, and the loss of organic matter, total nitrogen and total phosphorus in soil was over 50%. It is illustrates that the skidding operation of J-50 tractor caused very serious water and soil erosion. A great quantity of organic matters and nutrient substances were taken away. The change of the topsoil physical and chemical properties on skid trail in this test is obviously lower than that of the skidding operation of J-50 tractor. Especially in this test, the quantity of nutrient elements of nitrogen and potassium in the topsoil on skid trails slightly increased in comparison with the reference sample plot. This is very beneficial to the renewal of cutover area and the growth of remained trees. Therefore, in comparison with J-50 skidding tractor, the multifunctional wheeled skidding tractor is suitable for the skidding operation in the Northeast Forest Region in the aspect of environment. It has small disturbance and damage to forest soil, can effectively protect the ecological environment of forest, and will thus promote the sustainable development of forest in our country.

Although the multifunctional wheeled skidding tractor has small impact on the topsoil physical and chemical properties on skid trails after skidding operation, it still has some impact on the forest soil. Therefore, in order to further reduce the impact of tractor skidding operation on the forest ecological system, the skidding operation technology needs to be improved correspondingly. For example, reduce the forest land occupied by skid trails and the disturbance of skid trail construction on soil as much as possible when making the skid trail operation planning, choose skid trails reasonable and take relevant measures to prevent the water and soil erosion caused by rain wash, increase the density of forest road network to reduce the passing times of tractor and the disturbance and compaction on soil, and lay shrubs and branches on skid trails during skidding operation to reduce the damage to soil at the same. In addition, winter operation can also reduce the negative influence of skidding operation on forest soil. According to relevant researches [7-8], after the forest soil is compacted, the penetration resistance of soil is increased, the ventilation condition becomes worse, and the water which plants can directly absorbed from soil becomes less. This is very harmful to the growth of plants, and will make the soil become more likely to be eroded. Therefore, the skid trail should be treated after skidding operation without delay to improve the soil structure, improve the water holding and drainage capacity, ensure the physical properties of soil can be recovered, and thus make the vegetation on skid trails be recovered rapidly after skidding operation.

Acknowledgements

The authors would like to acknowledge the support of the Special Scientific Research Funds for Forest Non-profit Industry (Grant No. 201104007) and the Fundamental Research Funds for the Central Universities (Grant No. DL13BB10).

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