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INFLUENCE ON OPERATOR'S HEALTH OF HAND-TRANSMITTED VIBRATIONS FROM HANDLES OF A SINGLE-AXLE TRACTOR

Vlado Goglia[1], Zlatko Gospodaric[2], Dubravko Filipovic[2], Igor Djukic[1]

[1]Faculty of Forestry, University of Zagreb, Croatia
[2]Faculty of Agriculture, University of Zagreb, Croatia

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Abstract: The operators of the single-axle tractors are especially exposed to hand-arm transmitted vibrations. These vibrations can cause the complex of vascular, neurological and musculoskeletal disorders, collectively named hand-arm vibration syndrome. Among these, the most common disorder is vibration-induced white finger (Raynaud's phenomenon). The vibration levels were measured in three tractor's working conditions, namely idling, transportation and soil tillage. The vibration level on the handles was measured and analysed and the frequency spectra for the chosen working conditions were obtained. The frequency-weighted acceleration, given in m/s², was calculated and the obtained values are graphically presented. The measured vibration levels are then discussed with regard to the operator's daily exposure limits recommended by the ISO 5349. The vibration levels were much higher in the x and y directions than the z-direction in all working conditions. The vibration total values in idling, transportation and soil tillage were 3.37, 8.37 and 9.62 m/s², respectively. Results showed that the 10% of workers are exposed to a risk of vibration-induced white finger disorder of the hands after relatively short periods (3–4 years), if the tractor is used 8 hour per day in soil tillage and transportation at full load. Considering the criteria of the ISO 5349, the daily working time with the single-axle tractor should be limited in order to protect the operator and work schedules should be arranged to include vibration-free periods.

Address for correspondence: Prof. Vlado Goglia, Faculty of Forestry, Svetosimunska 25, 10000 Zagreb, Croatia. E-mail: goglia@hrast.sumfak.hr

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INTRODUCTION

Vibrations can produce a wide variety of different effects to the machine operators. The effects on the operator exposed to a high vibration level for a longer period of time are usually permanent in character and are therefore considered to be an occupational disease leading to invalidity [5, 6]. According to the statistics of the State Health Institute of the Republic of Croatia, vibrations accounts for 11.4% of the overall number of occupational diseases in the period from 1990 to 1997 [13]. Machine operators are usually exposed to two types of vibrations: whole-body vibrations transmitted via the seat or via the floor and feet, and hand-arm-transmitted vibrations [12]. The operators of the single-axle tractors are especially exposed to hand-arm transmitted vibrations. These vibrations can cause the well-known hand-arm vibration syndrome (HAVS), which includes vascular, neurological and musculoskeletal disorders. The performance of the single-axle tractor depends not only on the machine but also on the operator, because an operator has to walk behind the machine during work, except in transportation. If ergonomics aspects are not given due consideration, the performance of the man-machine system will be poor and

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effective working time will be reduced because of frequent or long rest periods, resulting in lower work output. On the other hand, due to heavy demand on the operator's biological systems, the machine operation may cause clinical or anatomical disorders and in the long run will affect the operator's health [20].

At present, there are about 86,500 single-axle tractors (also known as two-wheel, walking or hand tractors) in Croatia. On small farms these tractors often represent the only mechanical aid resource for the agricultural activity, mainly for vegetable production. Although the hand-transmitted vibrations is a very serious problem, little attention is paid to it. The intention of this research was to define the vibration exposure levels of the hand-transmitted vibrations from the handles of a single-axle tractor to the operator's hands and the operator's daily exposure limits.

MATERIAL AND METHODS

To quantify vibration exposure, measurements must be taken under representative conditions. Guidelines for measuring and evaluating human exposure and details of different analysis methods for the hand-arm transmitted vibrations are given in ISO 5349-1 and ISO 5349-2 [10, 11]. In the ISO 5349 standard recommendations, the most important quantity used to describe the magnitude of the vibrations transmitted to the drivers hands is root-mean square frequency-weighted acceleration expressed in m/s². In addition, it is strongly recommended that for additional purposes frequency spectra should be obtained. Acceleration values from one-third-octave band analysis can be used to obtain the frequency-weighted acceleration a_{hw}. It shall be obtained using:

$$a_{hw} = \left[\sum_{j=1}^{n} (W_j \cdot a_{wj})^2 \right]^{\frac{1}{2}} \qquad (1)$$

where a_{wj} is the acceleration measured in the one-third-octave band in m/s², and W_j is the weighting factor for the one-third-octave band.

In accordance with mentioned ISO standards, the three directions of an orthogonal co-ordinate system, in which the vibration accelerations should be measured, were as follows: Z-axis directed along the second metacarpus bone of the hand; X-axis perpendicular to the Z-axis (both these axes are normal to the longitudinal axis of the grip); Y-axis parallel to the longitudinal axis of the grip (Fig. 1). The inclination of the metacarpus bone when the hand grasped the grip was at 45º to the vertical.

For practical measurements, the orientation of the coordinate system may be defined with reference to an appropriate basicentric coordinate system originating in vibrating handle gripped by the hand. The evaluation of vibration exposure in accordance with ISO 5349 is based on a quantity that combines all three axes. This is the vibration total value ahv or weighted acceleration sum (WAS) and it is defined as the root-mean-square of the three component values:

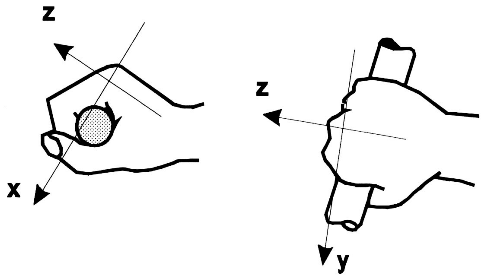

Figure 1. Orientation of the axes for the vibrations measurement (according to ISO 5349).

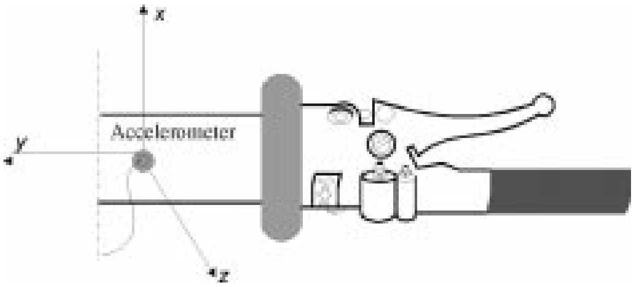

Figure 2. Accelerometer position during vibration measurement with marked directions.

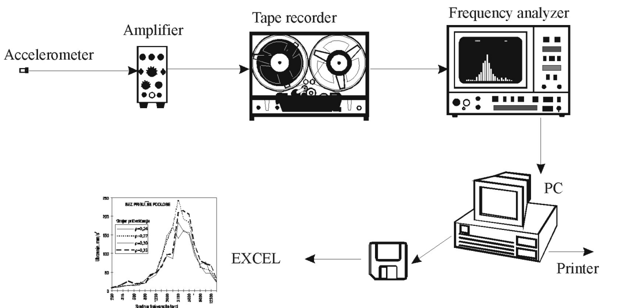

Figure 3. Schematic presentation of the equipment used for vibration measurements and analysis.

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (2)$$

where a_{hwx}, a_{hwy}, a_{hwz} are frequency-weighted acceleration values for the single axes.

The vibration exposure depends on the magnitude of the vibration total value and on the duration of the exposure. Daily exposure duration is the total time for which the hands are exposed to vibrations during the working day. The daily vibration exposure shall be expressed in terms of the 8-hour energy-equivalent acceleration or frequency-weighted vibration total value:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \qquad (3)$$

where T is the total daily duration of the exposure in s, and T0 is the reference duration of 8 h (28 800 s).

The vibration levels were measured at the handle of a single-axle tractor with three axes piezoelectric accelerometer mounted as presented in Figure 2. The vibration

Table 1. Technical characteristics of tested tractor.

Tractor characteristics	
Manufacturer	Labinprogres
Type	Super special lux
Serial No.	21838
Engine manufacturer	ACME motori
Engine type	ADN 54 W (4-stroke diesel)
No. of cylinders	1
Displacement, cm³	540
Power, kW	9.4
Maximal r.p.m., min^{-1}	3600
Transmission	Mechanical
Gear rates	4 forward, 2 reverse
Power take-off	Two shafts
Nominal r.p.m., min^{-1}	575 or 934
Tyres	5.00-12
Inflation pressure, bar	1.6
Total mass, kg	190

signals were pre-amplified, recorded and analysed in 1/3 octave band using a real time frequency analyser. All components of the measuring chain (shown in Fig. 3.), except PC, are Bruel&Kjaer products.

Measurements were carried out during September 2004 in the Tractor Testing Station of Agricultural Engineering Department, Faculty of Agriculture, University of Zagreb (45° 51’ N, 16° 04’ E), and analyses of results in licensed Laboratory for noise and vibration of Faculty of Forestry, University of Zagreb. A single-axle tractor manufactured in Croatia and commonly used by the farmers was selected for the study. Before testing, the tractor was examined and adjusted according to the manufacturer’s recommendations. Technical characteristics of the tested tractor are presented in Table 1. The vibration levels transmitted to the operator's hands were measured in three tractor's working conditions: in idling in a stationary condition and in two main activities of single-axle tractors in Croatia, transportation and soil tillage. In transportation, vibration levels were measured on an asphalt road at full load at the highest gear, and in soil tillage at full load in first gear. Transportation was carried out with the 500-kg payload trailer, and soil tillage with the rotary tiller powered by the tractor’s power take-off shift, with the working width of 800 mm and 24 tilling blades. For each working condition, five independent measurements were carried out. Based on these values, the arithmetic mean value of the acceleration values from one-third-octave band analysis and the frequency-weighted acceleration were calculated. Statistical analysis was performed on the measurement data using the Excel program.

RESULTS

Results of the measurements can be grouped as follows:

• acceleration values obtained from the one-third-octave band analysis for three working conditions and their presentation in accordance with ISO 5349,

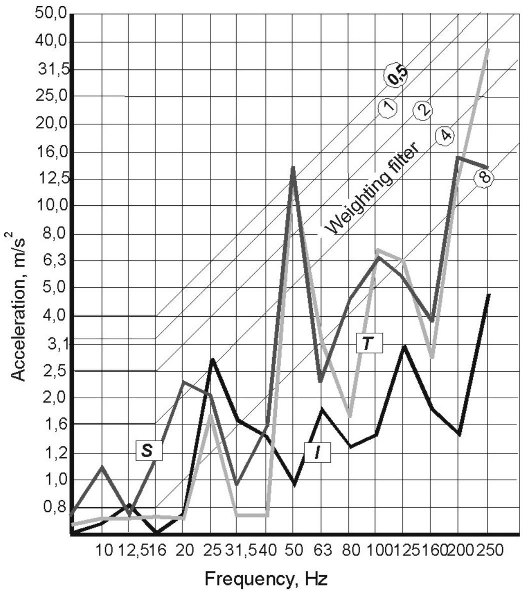

Figure 4. Graphic representation of vibration levels in x-direction (I - idling, T - transportation, S - soil tillage).

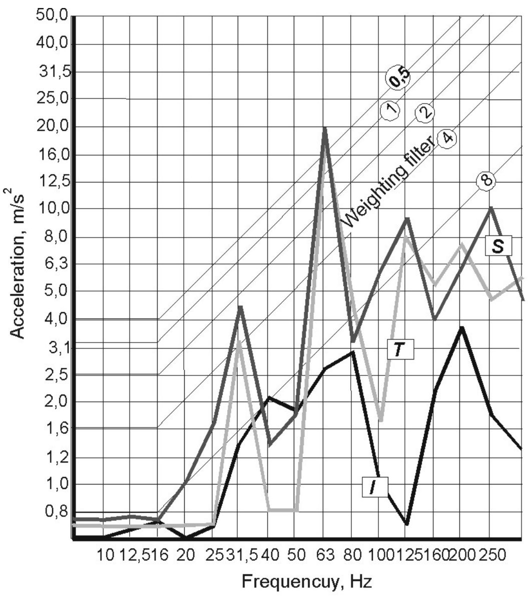

Figure 5. Graphic representation of vibration levels in y-direction (I - idling, T - transportation, S - soil tillage).

• frequency-weighted accelerations and the vibration total values for three working conditions - weighted acceleration sum (WAS) and their presentation in accordance with ISO 5349.

Acceleration values obtained from the one-third-octave band analysis. Frequency spectra were obtained for all three single axes and three working conditions. The results are graphically represented in Figures 4-6.

The acceleration values in the x-direction (Fig. 4) in transportation and soil tillage at full load in two one-third-octave band exceed the 4 h daily exposure limit, while in idling in one one-third-octave band. The maximum acceleration value in soil tillage was at the frequency of 50 Hz and this value even exceed the 0.5 h daily exposure

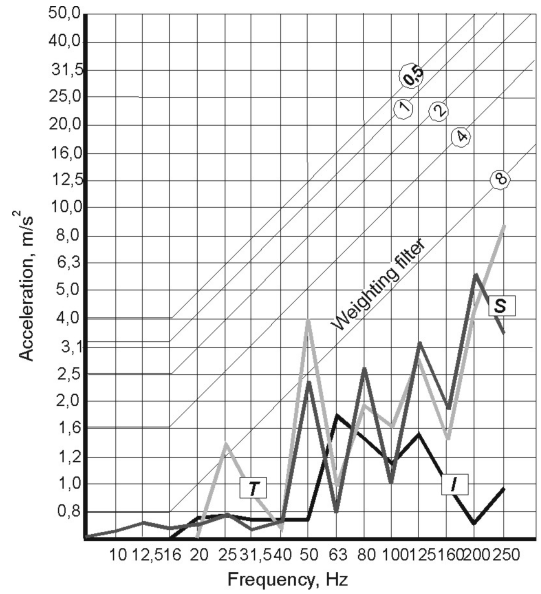

Figure 6. Graphic representation of vibration levels in z-direction (I - idling, T - transportation, S - soil tillage).

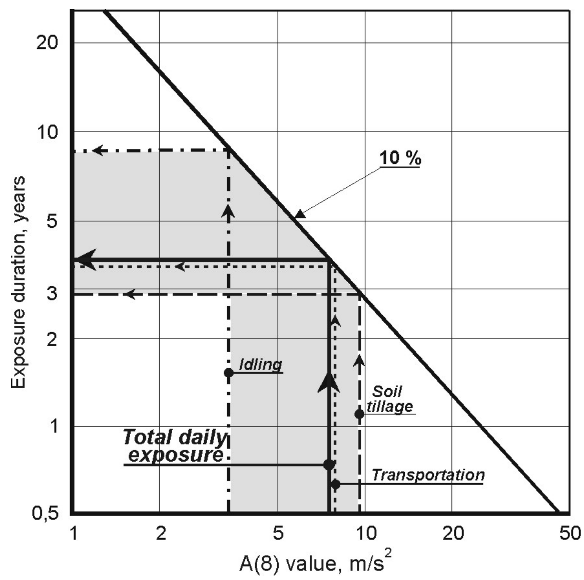

Figure 7. Vibration exposure for predicted % prevalence of vibration-induced white finger in a group of exposed persons (I - idling, T - transportation, S - soil tillage).

limit. In transportation, the maximum acceleration value was at the frequency of 250 Hz. The acceleration values in the y-direction (Fig. 5) in transportation and soil tillage at full load, also in two one-third-octave band, exceeded the 4 h daily exposure limit, while in idling in none of them. The maximum acceleration values in transportation and soil tillage were at the frequency of 63 Hz and also exceed the 0.5 h daily exposure limit. In the z-direction (Fig. 6) only in transportation acceleration value in two one-third-octave band (at 25 and 50 Hz) exceed the 8 h daily exposure limit. From Figures 4-6 it is evident that the much higher vibrations were in the x and y directions. The values of acceleration in soil tillage were similar or little lower in the x-direction than the values reported by Ragni *et al.* [17], but on the contrary, they found the lowest vibrations in the y-direction. Ying *et al.* [21] found that most vibrations was centralised in the frequency range from 0–200 Hz, and the most serious vibrations among the three directions was in the x-direction.

Frequency-weighted accelerations and the vibration total values. Frequency-weighted accelerations for all five independent measurements, their mean values and the vibration total values for three working conditions, are given in Table 2. The vibration total values (WAS values) and the operaters daily vibration exposure are graphically presented in accordance with ISO 5349 in Figure 7.

Table 2 shows that the highest vibration total value was observed in soil tillage. In transportation, the vibration total value was 13% lower and in idling in stationary condition 65% lower in comparison to soil tillage. Salokhe *et al.* [18] also studied vibration characteristic of two-wheel tractor in stationary condition, transportation and soil tillage, and also observed the maximum vibration intensities in soil tillage and the lowest in stationary condition. Considering the criteria of the ISO 5349, working conditions of the single-axle tractor at full load fall into the highest class of risk. Figure 7 shows that the 10% of workers are exposed to a risk of vibration-induced

Table 2. Evaluated vibration levels (WAS) for three working conditions in three axes, m/s^2.

Working condition	Acceleration direction	Measuring No.					Mean value	Standard deviation	WAS
		1	2	3	4	5			
Idling	x	2.46	2.53	2.39	2.44	2.50	2.46	0.05	3.37
	y	1.96	2.08	2.26	2.06	2.04	2.08	0.11	
	z	0.96	0.77	1.07	0.75	1.35	0.98	0.25	
Transportation	x	4.54	4.22	8.04	5.02	4.21	5.21	1.62	8.37
	y	6.92	5.29	9.12	5.41	4.84	6.32	1.75	
	z	1.77	1.86	1.69	1.67	1.71	1.74	0.07	
Soil tillage	x	6.45	6.12	4.79	4.01	7.32	5.74	1.33	9.62
	y	7.05	6.48	6.93	9.20	8.04	7.54	1.09	
	z	1.49	1.24	2.16	1.66	1.83	1.68	0.35	

white finger after relatively short periods (3–4 years), if the tractor is used 8 hours per day in soil tillage and transportation at full load. According to Ragni *et al.* [17], if these machines are used at least for 4 hours per day, the time expected for the appearance of the hand disorders is 3 years for the 10% of the operators.

DISCUSSION

The operators of the single-axle tractors are exposed to a high level of vibrations transmitted from the handles to the hands, arms and shoulders. The detrimental effects of the hand-arm vibrations on the operators have been known for a long time. The symptoms, which include effects on peripheral circulation, the peripheral nerves or the musculoskeletal system, have also been recognised as important occupational disorders. The complex of vascular, neurological and musculoskeletal disorders occurring in the upper limbs of vibration-exposed machine operators is called hand-arm vibration syndrome. For the most common vascular disorder, vibration-induced white finger, the principal symptom and sign involves attacks of well-demarcated finger blanching (Raynaud's phenomenon). The low finger systolic blood pressure following cooling is indicative of vibration-induced white finger and zero finger systolic blood pressure can confirm an attack of Raynaud's phenomenon [16]. For neurological disorders, some symptoms can exist without detectable signs and some signs can exist without symptoms; numbness and tingling are commonly reported but neurological changes may be present without these symptoms [7]. According to Lundborg *et al.* [14], sensory and motor dysfunction can be explained by injury to peripheral structures, but could also be due to changes in cortical somatotopic mapping of the hand in the brain. Hagberg [8] described the clinical assessment of musculoskeletal disorders among vibration-exposed workers and the reported effects on bone are osteoporosis and cysts in the hands, while Necking *et al.* [15] reported that reduced strength in abduction of the index finger is an important indicator of intrinsic muscular dysfunction in workers with hand-arm vibration syndrome.

Dong *et al.* [3] associated the hand-arm vibration syndrome with prolonged exposure to vibrations transmitted to the human hand-arm system from vibrating machines. According to Bovenzi [1], there are too few epidemiology data to enable reliable conclusions to be drawn about exposure-response relationships for disorders caused by hand-transmitted vibrations. The proposal of exposure-response relationships for vibration-induced disorders has been included in an annex to the ISO 5349 [9]. According to this annex, the severity of the biological effects of hand-transmitted vibrations during work is influenced by: the frequency of vibrations, its magnitude and the duration of exposure; the arm and body position during exposure; the type and condition of the vibrating machinery; and the direction of vibrations transmitted to the hand. However, the vibration exposure required to cause the vibration-induced disorders is today not known, either with respect to vibration intensity, frequency, or with respect to daily exposure time and the total exposure period [2, 19].

The duration of exposure needed to produce hand-arm vibration syndrome cannot be readily defined. This is due not only to different individual susceptibilities to vibrations, but also to the different physical characteristic of the vibration exposure [4]. Permanent vibration exposures cause negative physical effects that may lead to occupational diseases. In order to protect against hand-arm vibrations, technical and medical measures must be taken into account [12]. A person found to have developed disorders induced by vibrations should not be returned to the same vibration exposure or work without any changes expected to lessen the risk [7]. Therefore, it is necessary that persons who are responsible for occupational health and safety to take preventive measures.

CONCLUSIONS

Based on the measurement results, it is quite certain that the vibrations transmitted from the handles of the single-axle tractor to the operator's hands can cause a variety of vascular, neurological and musculoskeletal disorders collectively named hand-arm vibration syndrome. The 10% of workers are exposed to a risk of vibration-induced white finger after relatively short periods (3 or 4 years), if the tractor is used 8 hours per day in soil tillage and transportation at full load. According to the existing criteria, the daily working time with the single-axle tractor should be limited in order to protect the operator and work schedules should be arranged to include vibration-free periods.

REFERENCES

1. Bovenzi M: Exposure-response relationship in the hand-arm vibration syndrome: an overview of current epidemiology research. *Int Arch Occup Environ Health* 1998, **71**, 509-515.

2. Burström L, Sörensson A: The influence of shock-type vibrations on the absorption of mechanical energy in the hand and arm. *Int J Ind Ergon* 1999, **23**, 585-594.

3. Dong RG, Rakheja S, Schoopper AW, Han B, Smutz WR: Hand-transmitted vibration and biodynamic response of the human hand-arm: A critical review. *Crit Rev Biomed Engin* 2001, **29**, 393-1439.

4. Friden J: Vibration damage to the hand: Clinical presentation, prognosis and length and severity of vibration required. *J Hand Surg Br Eur Vol* 2001, **26**, 471-474.

5. Goglia V: Ergonomic parameters of forest mechanisation – measuring and evaluation problems. *Mehanizacija sumarstva* 1996, **22**, 209-217.

6. Gorski T, Zamuslowska S: Vibration syndrome and occupational exposure. *Medicina Pracy* 1998, **49**, 527-534.

7. Griffin MJ, Bovenzi M: The diagnosis of disorders caused by hand-transmitted vibration: Southampton Workshop 2000. *Int Arch Occup Environ Health* 2002, **75**, 1-5.

8. Hagberg M: Clinical assessment of musculosceletal disorders in workers exposed to hand-arm vibrations. *Int Arch Occup Environ Health* 2002, **75**, 97-105.

9. ISO 5349: *Mechanical vibration – guidelines for the measurements and assessment of human exposure to hand-transmitted vibration. Part 1: General requirements.* International Standard Organization, Geneva 1986.

10. ISO 5349-1: *Mechanical vibration – measurement and evaluation of human exposure to hand-transmitted vibration. Part 1: General requirements*. International Standard Organization, Geneva 2001.

11. ISO 5349-2: *Mechanical vibration – measurement and evaluation of human exposure to hand-transmitted vibration. Part 2: Practical guidance for measurement at the workplace*. International Standard Organization, Geneva 2001.

12. Issever H, Aksoy C, Sabuncu H, Karan A: Vibration and its effects on the body. *Med Princ Pract* 2003, **12**, 34-38.

13. Kacian N: Occupational diseases in Croatia. *Work Saf* 1999, **3**, 83-89.

14. Lundborg G, Rosen B, Knutsson L, Holtas S, Stahlberg F, Larsson EM: Hand-arm vibration syndrome (HAVS): Is there a central nervous component? An fMRI study. *J Hand Surg Br Eur Vol* 2002, **27**, 514-519.

15. Necking L, Friden J, Lundborg G: Reduced muscle strength in abduction of the index finger: An important clinical sign in hand-arm vibration syndrome. *Scand J Plastic Reconstr Surg Hand Surg* 2003, **37**, 365-370.

16. Palmer KT, Griffin MJ, Syddall H, Cooper C, Coggon D: The clinical grading of Raynaud's phenomenon and vibration-induced white finger: relationship between finger blanching and difficulties in using the upper limb. *Int Arch Occup Environ Health* 2002, **75**, 29-36.

17. Ragni L, Vassalini G, Xu F, Zhang LB: Vibration and noise of small implements for soil tillage. *J Agric Eng Res* 1999, **74**, 403-409.

18. Salokhe VM, Majumder B, Islam MS: Vibration characteristic of a power tiller. *J Terramechanics* 1995, **32**, 181-197.

19. Tewari VK, Dewangan KN, Karmakar S: Operator’s fatigue in field operation of hand tractors. *Biosys Eng* 2004, **89**, 1-11.

20. Tiwari PS, Gite LP: Physiological responses during operation of a rotary power tiller. *Biosys Eng* 2002, **82**, 161-168.

21. Ying Y, Zhang L, Xu F, Dong M: Vibratory characteristic and hand-transmitted vibration reduction of walking tractor. Transactions *ASAE* 1998, **41**, 917-922.