# HAND TRANSMITTED MECHANICAL VIBRATIONS AND SHOCKS TO OPERATORS OF SINGLE-AXLE TRACTOR DURING FIELD OPERATIONS

**BY**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.**

**2013**

## ABSTRACT

This study was conducted using both field experiments and structured questionnaires to investigate the influence of hand transmitted mechanical vibrations and shocks experienced by operators from handles of a single-axle tractor and determine an optimum operator's daily exposure limits in field conditions. The field experiments were conducted at Kilimanjaro Agricultural Training Centre (KATC). Four different makes of single-axle tractors were studied, namely: AMEC S 1100$A_2$ (distributed by District Councils), GREAVES GS-15 DIL (supplied by SUMAJKT), KUBOTA K120 and YANMAR TF110ML (supplied by MAFC to Training Institutes) and five experienced single-axle tractor operators were chosen for the field experiments.

The results show that the magnitude of vibration during tillage operation varies between 6.481 m/$s^2$ at 1.54 km/hr to 7.834 m/$s^2$ at 4.51 km/hr for AMEC; 7.908 m/$s^2$ at 1.95 km/hr to 8.442 m/$s^2$ at 5.70 km/hr for GREAVES; 5.350 m/$s^2$ at 1.11 km/hr to 7.856 m/$s^2$ at 2.92 km/hr for KUBOTA; and 6.012 m/$s^2$ at 1.04 km/hr to 10.263 m/$s^2$ at 7.14 km/hr for YANMAR. The magnitude of vibration during rota-puddling operation varies between 5.817 m/$s^2$ at 1.54 km/hr to 6.330 m/$s^2$ at 4.51 km/hr for AMEC; 6.033 m/$s^2$ at 1.95 km/hr to 7.739 m/$s^2$ at 5.70 km/hr for GREAVES; 4.250 m/$s^2$ at 1.11 km/hr to 4.445 m/$s^2$ at 2.92 km/hr for KUBOTA and 5.271 m/$s^2$ at 1.04 km/hr to 5.606 m/$s^2$ at 2.14 km/hr for YANMAR. The magnitude of vibration during transportation operation varies between 10.067 m/$s^2$ at 1.95 km/hr to 10.234 m/$s^2$ at 5.70 km/hr for GREAVES; 6.013

m/s$^2$ at 1.11 km/hr to 6.871 m/s$^2$ at 2.92 km/hr for KUBOTA and 5.622 m/s$^2$ at 1.04 km/hr to 6.903 m/s$^2$ at 2.14 km/hr for YANMAR.

The results further show that, the vibration acceleration total values ($a_{hv}$) in three operational modes exceed both suggested Exposure Action Value (EAV) and Exposure Limit Value (ELV). The expectation for 10% operators to show symptoms of vibration-induced disorders for single-axle tractor operators working at full load for 8-hours per day in three operational modes are shown as 3 to 4 years for GREAVES operators, 4 to 5 years for AMEC and YANMAR operators and 5 to 7 years for KUBOTA operators.

Structured questionnaires were administered to operators in two irrigation schemes; Lower Moshi in Kilimanjaro Region and Leki Tatu in Arusha Region. During field survey, single-axle tractor operators agree on the physiological or psychological fatigue experienced during operations. The fatigue was due to lack of proper training and skills on the required degree of interface between human-machine systems (coupling); exposure to extreme solar radiation; exposure to high magnitude of vibration through handles; use of extra energy to control the tractor and manoeuvre at headlands. The study results shows the presence of symptoms of vibration-induced disorders in its preliminary stages that if not diagnosed and attended in time, may develop to disorders that may result to impairment of life quality and disability of the affected operator. Therefore, the study demonstrates the susceptibility of operators to the effects of HAVS. The study recommends that further studies are required to be carried out to characterize vibration magnitude of single-axle tractors used in Tanzania so that best practice and guidelines can be established.

# DECLARATION

I, **ALI SHAIB HASSAN**, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my original work and that it has never been submitted for degree award in any other university.

Signature …………………………………. Date …………………………..

Ali Shaib Hassan

**(MSc. Student)**

The above declaration is confirmed.

Signature …………………………………. Date …………………………..

Prof. S. M. Mpanduji

**(Supervisor)**

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## ACKNOWLEDGEMENT

I wish to express my sincere gratitude's to my supervisor Prof. S. M. Mpanduji for his support in terms of guidance and advices rendered to me during the whole period of my research work. The knowledge and assistance acquired made possible to follow successful the schedule for research work. Thankful to the Principal, Arusha Technical College for the financial support granted to me to facilitate my study.

I am grateful to Eng. A. J. Pyuza, Principal of Kilimanjaro Agricultural Training Centre for permission to pursue my study at KATC and the support provided for accommodating in Institute's hostel during data collection. Special thanks are extended to Director of Machinery Testing at CAMARTEC; Mr. Kahana and Assistant Head of Section Agricultural Machinery at KATC; Mr. E. D. Mziray for technical advises provided to facilitate my research. Sincere thanks are extended to the operators participated both, during field experiments and those interviewed to gather information through structured questionnaires.

I wish to express my sincere and deepest appreciation to my Wife (Biena Amanzi) and family at large, for tolerance from silent suffering caused by my absence from home. Their patience and inspiration motivated me in both good and difficult times. Lastly, I wish to appreciate the contribution made by fellow students and staff of the Department of Agricultural Engineering and Land Planning on form of advices, physical assistance and material support.

# DEDICATION

To my son, **Hafidhi Ali Shaib** who passed away while corrects my dissertation for final submission and young brother **Abdallah Ali Abdallah** (Kakweti) who passed away when pursuing my course work at SUA. May Almighty God Forgive Them and Rest Their Soul in Eternal Peace. To my parents who strive hard in small farms with late technology in a desire to acquire improved livelihood, sustainable life and support children's development.

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| $a_{hv}$ | Vibration acceleration total value |
| A(8) | 8-Hour energy equivalent acceleration |
| ACGIH | American Conference of Governmental Industrial Hygienists |
| ANOVA | Analysis of Variance |
| ANSI | American National Standard Institute |
| ASDP | Agricultural Sector Development Programme |
| ATC | Arusha Technical College |
| BS | British Standards |
| CAMARTEC | Centre for Agricultural Mechanization and Rural Technology |
| CCOSH | Canadian Centre for Occupational Safety and Health |
| CTS | Carpal Tunnel Syndrome |
| DAELP | Department of Agricultural Engineering and Land Planning |
| DEAV | Daily Exposure Action Value |
| DELV | Daily Exposure Limit Value |
| $D_y$ | Lifetime exposure of hand transmitted vibration in years |

| | |
|---|---|
| EAV | Exposure Action Value |
| ELV | Exposure Limit Value |
| FAO | Food and Agricultural Organization |
| GDP | Gross Domestic Product |
| HAVS | Hand-Arm Vibration Syndrome |
| HTV | Hand Transmitted Vibration |
| ICHAV | International Conference of Hand-Arm Vibration |
| ILO | International Labour Organization |
| ISO | International Standards Organization |
| KATC | Kilimanjaro Agricultural Training Centre |
| LMIS | Lower Moshi Irrigation Scheme |
| MAFC | Ministry of Agriculture Food Security and Cooperatives |
| MTN/VM | Monitran/Vibration Meter |
| NIOSH | National Institute of Occupational Safety and Health |
| NSGRP | National Strategy for Growth and Reduction of Poverty |
| R.M.S | Root Mean Square value |

| | |
|---|---|
| SPSS | Statistical Package for Social Sciences |
| TAMS | Tanzania Agricultural Mechanization Strategy |
| TanRice | Tanzania Rice Project |
| TBS | Tanzania Bureau of Standards |
| TLV | Threshold Limit Values |
| TPC | Tanganyika Planting Company |
| UNIDO | United Nation Industrial Development Organization |
| URT | United Republic of Tanzania |
| VWF | Vibration-induced White Finger |
| WAS | Weighted Acceleration Sum |
| $x_h$ | Vibration acceleration transmitted to the hand in *x*- direction |
| $y_h$ | Vibration acceleration transmitted to the hand in *y*- direction |
| $z_h$ | Vibration acceleration transmitted to the hand in *z*- direction. |

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background Information

Agriculture is the second greatest source of employment worldwide after services and the most important sector for female employment in many countries especially in Africa and Asia (ILO, 2010). Tanzania has a total area of about 94.5 million hectares of which 44 million hectares are arable lands. Agricultural economic activities contribute about 26.5% of the Gross Domestic Product (GDP) and 30% of the export earnings and provide employment to about 80% of the active working populations, out of which 56% are women (URT, 2009a).

Tanzania’s agriculture is passing through transformation from traditional farming to modern and mechanized farming systems. Despite the impressive macroeconomic achievements caused by different reform strategies, such as Tanzania Development Vision 2025, National Strategy for Growth and Reduction of Poverty (NSGRP) popularly known as “MKUKUTA”, the Agricultural Sector Development Strategy (ASDS), and Tanzania Agricultural Mechanization Strategy (TAMS), agricultural growth and rural poverty reduction remains most important socially and economically and continue to pose great challenges to developing economies like Tanzania (URT, 2006). The falling of labour and land productivity which are considered to be resulting from application of poor technology and dependency on unreliable and irregular weather conditions, have constrained agricultural sector development in Tanzania.

Agricultural mechanization is the application of mechanical technology and increased power to agriculture, in order to enhance the efficiency of human labour leading to intensified and increased productivity. Agricultural mechanization embraces the use of tools, implement and machines for agricultural land development, crop production, harvesting and preparation for storage, storage, and on-farm processing. This includes the use of various types of power sources, animal- and human-powered implement and tools, and other methods of energy conversion. According to FAO and UNIDO (2008), levels and types of improved mechanical technologies need to be compatible with local, agronomic, socio-economic, environmental and industrial conditions.

As an implementation to the attribute of improved livelihood and enhancing agricultural productivity, as defined by the Tanzania Development Vision 2025; the Tanzania Government, through various agricultural strategies such as NSGRP, ASDS and the “Kilimo Kwanza” initiative is promoting the use of single-axle and other tractors in the efforts of transforming agricultural practices from relying on hand hoe to relying on mechanized agricultural practices. The introduction of single-axle tractors are seen as agricultural liberation to small and medium scale farmers. The demand for the single-axle tractors is increasing due to increased need to ensure timely accomplishment of various field operations in agriculture, awareness of its usefulness, extensive demonstrations, development of sales and service facilities and availability of matching equipment.

This is evident as is reflected in the importation and distribution trends of single-axle tractors, in which 3214 single-axle tractors were imported and distributed by independent suppliers between 2005/2006 and 2009/2010; among which a total of 2219 single-axle tractors were imported and distributed to farmers in 2009/2010 through District Councils and Cooperative Unions. Survey done by the Ministry of Agriculture, Food Security and Cooperatives (MAFC) in June 2011 found that there were about 4600 single-axle tractors in Tanzania (Appendix 4); and importation trend shows that about 200 single-axle tractors are added every year in the agricultural field (Shetto, 2011).

## 1.2 Justification

Single-axle (also known as two-wheeled, walking, hand or power tiller) tractors are used in agricultural land preparation under both dry and wet land conditions. They are particularly suitable for small fields, such as those owned by small and medium scale farmers in Tanzania. Increase in the up-keep cost of draught animals and the scarcity of labourers for timely performance of various agricultural operations has increased the demand for single-axle tractors in most parts of our country. However the use of single-axle tractors brings many challenges, the most significant challenge is the operator's exposure to hand transmitted vibrations that need to be addressed in order to realize the contribution of single-axle tractors to our society; socially and economically.

The operator of single-axle tractor has to endure various environmental stresses. The environmental stresses include all factors in the agricultural field, which have an effect on human–machine system. Among these factors, mechanical vibration is more important as it significantly accelerates fatigue and affects sensitivity and efficiency of the operator (Goglia *et al*., 2006; Sam and Kathirvel, 2006; Tewari *et al*., 2004). The operation with single-axle tractors involves lifting the rear portion of the machine to take sharp turns at the headlands. All the efforts combined with exposure to varying degrees of solar radiation, dusty environment and above all the severe hand vibrations cause a lot of stress on the operator resulting in physiological or psychological fatigue after the daylong operation (Tiwari and Gite, 2006). The human-machine system relationship comprises of very complicated mechanical structure and biological system. As Dong *et al.* (2012) report, the study of biodynamic responses of the hand-arm system to vibration is vital for understanding mechanisms of vibration-induced disorders.

Mechanical vibrations are in the form of oscillatory motion caused by the moving components of the machine and transmitted to a human body in contact with the machine. As Ying *et al.* (1998) reveal; the mechanical vibrations are made up of different frequencies occurring simultaneously in which the human body is not equally sensitive to all frequencies. Exposure to high magnitudes of mechanical vibrations may cause microscopic damage to the hand-arm systems which starts as a pain and progressively develop to a complex vibration-induced disorder as exposure to vibration continues. As Kao, (2003) observed vibration-induced disorders in form of muscular fatigue has adverse health effects (injury or disease) to soft body tissue, nerves, bones and joints, muscle tendons and can affect the nervous system. Thus, measuring the magnitude of hand transmitted vibration that an operator is exposed to, in the actual working field is essential in order to understand any musculoskeletal disorder caused by awkward posture and determine reasonable workload in different work conditions (Tewari *et al*. 2004).

If all the performance parameters of single-axle tractor are not given due consideration, the performance of the human-machine system relationship will be poor and the effective working time will be reduced because of frequent or long downtime periods, resulting in lower work output (Tewari *et al.* 2004). A safe and comfortable working environment for operators becomes an important consideration in single-axle tractor operations. Several studies have been done to investigate the vibration characteristics of the hand-arm system. Most of these studies were done on shakers under controlled laboratory conditions using sinusoidal vibration, random vibration and shock vibration (Dong *et al.*, 2004; Burstro¨m and Sörensson, 1999; Palmear *et al*., 1999; Gurram *et al*., 1994). However, few studies of vibration transmission in the hand-arm system have been reported under actual field conditions (Dewangan and Tewari, 2008; Palmear *et al*. 2001).

The current study was conducted in the actual field environment using common working conditions; ploughing in a dry soil condition (tillage), cultivating using rotary tiller in waterlogged soil condition (rota-puddling) and transportation on farm roads. The emphasis was to quantify the intensities of mechanical vibration during operation, in order to promote a preventive occupational safety and health by raising awareness of the hazards and risks associated with single-axle tractors and how they can be effectively managed and controlled to prevent accidents and diseases that tends to increase discomfort and early fatigue to operators.

## 1.3 Objectives of the Study

### 1.3.1 Main Objective

The main objective of this study was to investigate the influence of hand transmitted mechanical vibrations and shocks experienced by operators from handles of a single-axle tractor and determine an optimum operator’s daily exposure limits in field conditions.

### 1.3.2 Specific Objectives

Specifically the objectives of the study include:

i. Investigate the levels of hand transmitted mechanical vibration experienced by operators from single-axle tractors in field conditions.

ii. Investigate the influence of hand transmitted mechanical shocks experienced by operators.

iii. Recommend a safe practice as an optimum operator’s daily exposure limits in reference to the international standards.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Introduction

In order to fulfil specific objectives of the study, reviews were made through different literature and research studies to acquire the basic concept of mechanical vibration, theory of hand transmitted vibration, hand-arm vibration syndrome and the guideline and standards relating to vibration exposure at workplaces. The guidelines and standards considered in the review are those developed by Tanzania Bureau of Standards (TBS), Centre for Agricultural Mechanization and Rural Technology (CAMARTEC), ISO 5349 (2001a,b), BS 6842 (1987), Directive 2002/44/EC, ANSI S2.70 (2006) and American Conference of Governmental Industrial Hygienists (ACGIH).

### 2.2 The Basic Concepts of Mechanical Vibration

A mechanical system is said to undergo vibrations, when its component parts experience periodic oscillations about a statically equilibrium position. In some cases, mechanical vibration is advantageous, but its presence is generally undesirable due to structural damage associated with cyclical fluctuation of loading, physical discomfort to personnel, associated with the system and noise generated (Scarlett *et al.*, 2005; Hibbeler, 1989).

A four-stroke, single-cylinder diesel engine is the source of power in single-axle tractors. The dynamically unbalanced single cylinder engine is the major source of mechanical vibration, and the magnitude of vibration increases at the handle grip due to the cantilever design of handles. In hand transmitted vibration, the handle of a machine or the surface of a work piece vibrates rapidly, and this motion is transmitted into the hand, arm and shoulders. Sanders and McCormick (1987) demonstrate that the duration and severity of the vibration will depend on the relation between external forces and the mechanics of the system.

A tendency of mechanism to vibrate is assessed by three quantities (Fig. 1):

i. The maximum displacement from the central position (Amplitude-A);
ii. The time taken to complete one cycle of vibration (Frequency);
iii. The measure of the instant at which a vibration passes through the central position (Phase-φ).

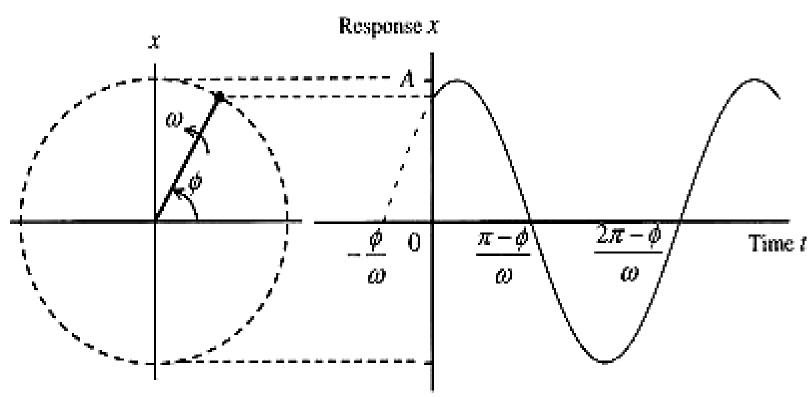



**Figure 1: Sinusoidal vibration (Sanders and McCormick, 1987).**

Most vibration transducers produce an output that is related to acceleration; therefore, acceleration in root-mean squares (RMS) has traditionally been used to describe hand transmitted vibration ($a_{hv}$). RMS relates to vibration energy and hence the vibration damage potential. The instantaneous equations representing sinusoidal motion are as follows:

$$y = A sin(\omega t + \theta) \quad \text{.......} (1)$$

$$v = A\omega \cos(\omega t + \theta) \quad \text{.......} (2)$$

$$a = -A\omega^2 \sin(\omega t + \theta) \quad \text{.......} (3)$$

Thus

$$a = -\omega^2 y \quad \text{.......} (4)$$

Therefore:

$$a_{hav} = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad \text{.......} (5)$$

Where: $y$ = Vibration displacement, (m); $A$ = Amplitude, (m); $\omega$ = Angular velocity, (rad/sec); $T$ = Time, (Sec); $\theta$ = Initial angle, (rad); $V$ = Velocity, (m/sec); $a$ = Vibration acceleration, (m/s$^2$); $a_{hav}$ = Resultant of vibration acceleration, (m/s$^2$); $a_x$ = Vibration acceleration in $X_h$-axis, (m/s$^2$); $a_y$ = Vibration acceleration in $Y_h$-axis, (m/s$^2$); $a_z$ = Vibration acceleration in $Z_h$-axis, (m/s$^2$).

Mechanical systems are dynamic at varying degree of frequencies, thus their motion in response to an external force depends on the nature of the exciting forces and the unpredictable dynamic characteristics of their mechanical structure (Fig. 2). In order to understand the usefulness of concepts of mechanical vibration in various mechanical systems, the knowledge of the interactions between force and mechanical structures is a prerequisite. Dong *et al*. (2007) modelled a biodynamic response distribution of fingers and palm of hand-arm system and demonstrated that concepts on studies of engineering materials fatigue may be applied in the study of the biodynamic system of the hand-arm system.

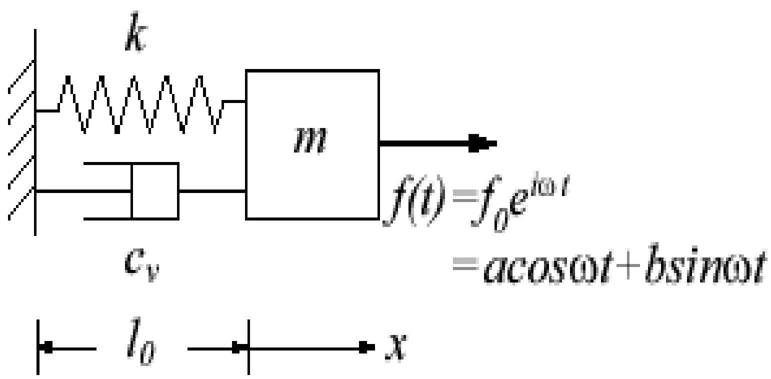



**Figure 2: Damped forced vibration in mechanical systems**

The equation of motion can be analyzed using the Newton's second law of motion, $F = ma$ with the aid of free body diagram (Fig. 3). In engineering systems, the function *f(t)* is the harmonic excitation in which the solution for the displacement *x(t)* depends on the vibration embedded in a design (free vibration) and the nature of the forcing function shortly termed as complementary and particular solutions respectively.

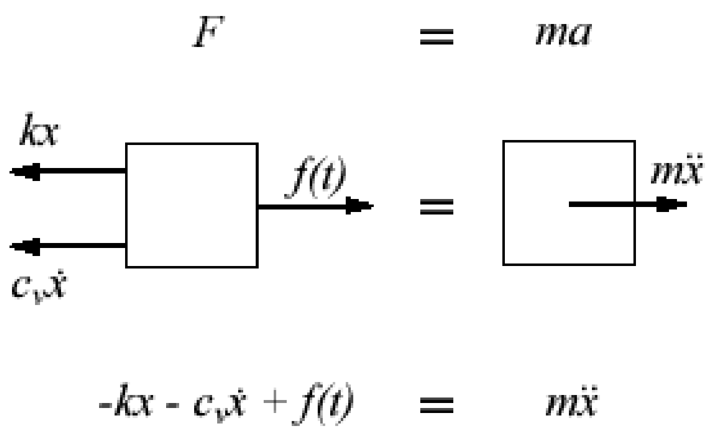



**Figure 3: Free Body Diagram of damped forced vibration system**

The particular solution is of the form (Eqn. 6):

$$X_p(t) = \left( {f_0}/{(k^2 - m^2\omega^2)} \right) Cos\omega_n t \quad \text{.......................................} \quad (6)$$

If the initial conditions of the system are defined by the Equation (7):

$$\begin{cases} X(t=0) = X_0 \\ \dot{X}\,(t=0) = V_0 \end{cases} \quad \text{..........................................................................} \quad (7)$$

Then; the general solution representing the displacement of the system becomes:

$$X(t) = X_0 Cos\omega_n t + {V_0}/{\omega_n}\, Sin\omega_n t + \left( {f_0}/{(k^2 - m^2\omega^2)} \right) Cos\omega_n t \quad \text{.........} \quad (8)$$

It is observed in Equation (8) that, under the presence of forcing function into the system, the displacement amplitude tends to increase linearly with time.

## 2.3 Theory on Hand Transmitted Vibration

The Directive 2002/44/EC of the European Parliament on the minimum health and safety requirements defines "hand-transmitted vibration" as "*the mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological and muscular disorders*" (EC, 2002). Scarlett *et al.* (2005) observe that hand transmitted vibration is a common form of segmental vibration experienced in work settings when a person holds or guides a vibrating tool or machine with their hand(s), and vibration is transmitted from the tool to the hand(s) and along the arm(s).

Long term exposure of human body to vibration leads to serious health problems, the severity of the effect of vibration to the body of an operator will largely depend on the magnitude of vibration, distribution of the motion within the body, vibration frequency, direction and duration (Scarlett *et al.* 2002; ISO 5349-1, 2001a). Various studies report differently on sources of hand transmitted vibration in single-axle tractors. The handle vibration in the hand operated tilling machines was mainly due to the reciprocating motion of the main moving parts (Araya, 1986). Jiao *et al*. (1989) observed that the major excitations of the hand transmitted vibration of single-axle tractor are the unbalanced inertia force of the engine and the unevenness of the farm surface.

## 2.4 Hand-Arm Vibration Syndrome (HAVS)

The occupational disorder associated with prolonged exposure to hand-transmitted vibration is referred to as 'Hand-Arm Vibration Syndrome' (HAVS) or commonly known as Vibration-induced White Finger (VWF) (Griffin *et al*., 2003; Griffin and Bovenzi, 2002; Bovenzi, 1998). The HAVS is not a single disease, but a collective term representing all disorders associated with vibration exposure including vascular, neurological and musculoskeletal disorders (Griffin *et al*., 2003; Bovenzi, 2000). As Nelson (2004) observes, the risks for different people would vary for each component of HAVS depending on other factors such as individual predisposition, any pre-existing disease and various personal and environmental factors.

The causes of HAVS or VWF include, among others, operating technique, grip and feed force, posture, temperature, humid condition and the exposure to vibration (NIOSH, 1989). VWF develops in workers who use hand-held power tools and equipment (Ying *et al.* 1998). The syndrome affects the nerves, blood vessels, muscles and joints of the hand, wrist and arm (Tewari *et al.*, 2004). The time taken for VWF to appear (latent interval) depends on the level of the exposure for the individual operator (Chaturvedi *et al.*, In Press). In early stage, the vibration-induced disorders appear as symptoms that if not diagnosed may develop to disorders that can result in disability of the affected person, in loss of body strength, working capability and impairment of life quality.

The operators of the single-axle tractors are exposed to a high level of vibration arising from the dynamic interactions between the tractor implement and agricultural field. As Welcome *et al*. (2004) reveal, the symptoms recognized to cause occupational diseases include the occasional numbness and tingling in fingers, whitening (blanching) of fingers, pain when exposed to cold and pain when blood circulation returns to the fingers, reduced grip strength and reduced finger flexibility. Other symptoms include the effects on peripheral circulation, the peripheral nerves or the musculoskeletal system (Tewari *et al.*, 2004). However, as reported by Burstro¨m and Sörensson, (1999) it is not known to what magnitudes of vibration intensity, frequency, daily exposure time and the total exposure period are required to cause the vibration-induced disorders.

During the operations of single-axle tractors the load on the operator increases with the increase of occupational hazards and diseases; which impair the performance of the operator (Salokhe *et al.,* 1995). Thus, the fatigue and discomfort subjected to human beings are due to not only physical labour, but also vibration. Therefore, vibration plays major role in operator's fatigue contribution in the field (Dewangan and Tewari, 2008). Furthermore, the operator has to apply force to manoeuvre the tractor, which further increases fatigue (Tiwari and Gite, 2006). Various studies conclusively have shown that exposure to hand transmitted vibration lead to vascular, neurological and musculoskeletal disorders (Bovenzi, 2000; Palmear *et al*., 1999; Griffin, 1996; Gemne *et al*., 1993).

### 2.4.1 Vascular Disorders

Vascular disorder is the most common healthy effect associated with hand transmitted vibration commonly known as Raynaud's phenomenon. It is characterized by narrowing small blood vessels of the hand that inhibits blood flow through the hands and finger, causing fingers to become white, cold and numb that results in weak pain and malfunctioning (Griffin and Bovenzi, 2002; Griffin, 2006; Palmear *et al*., 2007).

The stages of vascular disorder are based on the proposed scale at Stockholm workshop (Table 1).

**Table 1: Stockholm Workshop Classification Scale for Vascular Disorders**

**Stockholm workshop classification scale for cold induced vascular (blood flow) symptoms in fingers with Hand-Arm Vibration Syndrome**

| Stage | Grade | Description |
|---|---|---|
| **0** | None | No Attacks |
| **1** | Mild | Occasional attacks affecting only the tips of one or more fingers |
| **2** | Moderate | Occasional attacks affecting finger tips and middle of the finger and rarely also the finger parts close to the palm. |
| **3** | Severe | Frequent attacks affecting most fingers |
| **4** | Very Severe | Same symptoms as in stage 3 with degenerate skin changes in the finger tips. |

Source: Gemne *et al*. (1987)

### 2.4.2 Neurological Disorders

Neurological disorder is the hand and arm nerve effects due to exposure of vibrating objects. The affected worker experiences tingling and numbness in the fingers and hands; reduced sensation of touch and temperature and affected finger dexterity (Griffin and Bovenzi, 2002). Table 2 shows the stages of neurological disorder as proposed by Stockholm workshop classification scale.

**Table 2: Stockholm Workshop Classification Scale for Neurological Disorders**

| Stockholm workshop classification scale for sensorineural changes in fingers due to Hand-Arm Vibration Syndrome | |
|---|---|
| **Stage** | **Symptoms** |
| **0SN** | Exposed to vibration but no symptoms |
| **1SN** | Intermittent numbness, with or without tingling |
| **2SN** | Intermittent or persistent numbness reduced sensory perception. |
| **3SN** | Intermittent or persistent numbness, reduced tactile discrimination and/or manipulative dexterity. |

Source: Brammer *et al*. (1987)

### 2.4.3 Musculoskeletal Disorder

Musculoskeletal disorder is associated with the damage of the muscles and bones in the hand and arms propagated by use of vibrating tools. The symptoms include loss of strength in the hands and pain in the arms, wrist or shoulder (Griffin and Bovenzi, 2002). Currently, there is no clearly established exposure-response relationship between vibration exposure and development of the disorder (Nelson, 2004; Friden, 2001; Bovenzi, 1998).

Vibration induced health conditions progress slowly. In early stages, it starts as a pain. As the vibration exposure continues and physical demand of tasks increases, then pain developed may increase the risk of injury or disease. The early diagnosis of disorders caused by hand-transmitted mechanical vibration helps to prevent the progression of disorders and serious disability (Griffin and Bovenzi, 2002). That is, pain noticed in the first health condition should be addressed in order to stop from injury development.

## 2.5 Carpal Tunnel Syndrome (CTS)

Carpal tunnel syndrome (CTS) is a nerve disorder which arises from compression of the median nerve passing through carpal tunnel of the wrist. Barcenilla *et al*. (2011); Palmaer *et al*. (2007); Kao (2003) suggests that exposure to certain occupational hand and wrist activities involving repetitive and forceful gripping such as excessive vibration, hand force and their combinations carry an increased risk of CTS. The earlier signs and symptoms resembles those of VWF causing pain, tingling, numbness, abnormalities in the skin sensation and weakness in parts of the hands, arms and shoulders. In severe CTS cases, weaknesses of the hand due to loss of muscle function are irreversible. Currently CTS is not included in the definition of HAVS.

### 2.6 Guidelines and Standards Related to Vibrations

The following guidelines, standards and evaluation methods for assessing hand-transmitted mechanical vibration and shocks were considered during the study: TBS, CAMARTEC, ISO 5349, Directive 2002/44/EC, BS 6842, ANSI S2.70 (2006) and ACGIH.

#### 2.6.1 Tanzania Bureau of Standards

Tanzania Bureau of Standards (TBS) was established under the Ministry of Industry, Trade and Marketing by a Parliamentary Act No. 1 of 1977 for the purpose of establishing National Standards in the fields of agriculture and food, chemicals, textiles, leather, environment, engineering and service industry. Currently, TBS has not developed standards relating to occupational safety and health for agricultural machinery safety or good practices in safeguarding and making agricultural mechanization safe and friendly. TBS is an affiliated member to the International Standard Organization (ISO); therefore, the risk assessments for hand transmitted vibrations need to conform to the International Standard ISO 5349 (2001a, b).

#### 2.6.2 Centre for Agricultural Mechanization and Rural Technology

The Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) is required to assess functional performance, suitability under varying field conditions and establish performance data as specifications for marketing and extension services and publish the results on all types of machinery and equipment intended for use in agricultural and rural development in Tanzania. However, since trade liberalization was initiated in Tanzania not all imported or locally manufactured machineries are being tested or follow the regular channel before being introduced into the market (URT, 2006).

### 2.6.3 The ISO 5349 (2001a) Standard

The International Organization for Standardization in 2001 developed ISO 5349-1 and ISO 5349-2 standards as guideline for measuring and evaluating human exposure and details of different analysis methods for the hand-arm transmitted vibrations. In the ISO 5349 standard recommendations, the most important quantity used to describe the magnitude of the vibrations transmitted to the operator's hands is the root-mean square frequency-weighted acceleration expressed in m/s². The frequency-weighted vibration is expressed as:

$$a_{hw} = \left[\sum_{j=1}^{n}(k_j a_{hj})^2\right]^{1/2} \qquad \text{..........................................} \qquad (9)$$

where; $k_j$ is the weighting factor for the jth octave; $a_{hj}$ is the root-mean square acceleration measured in octave bands used in m/s²; and n is the number of frequencies used in the octave band.

#### 2.6.3.1 Direction of Vibration

In accordance with ISO 5349 standards, the three directions of an orthogonal co-ordinate system, in which the vibration accelerations should be measured, are as follows: $z_h$-axis directed along the second metacarpus bone of the hand; $x_h$-axis perpendicular to the $z_h$-axis (both axes are normal to the longitudinal axis of the grip i.e. transverse); $y_h$-axis parallel to the longitudinal axis of the grip (Fig. 4). The system is generally rotated in the *y*-*z* plane so that the *y*-axis is parallel to the handle axis.

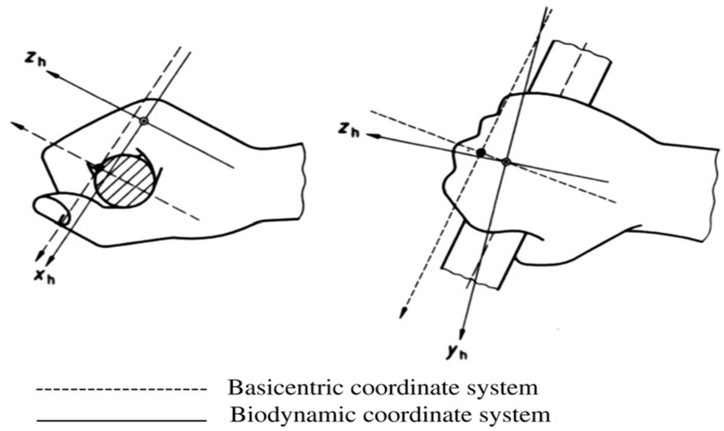



**Figure 4: Orientation of the axes for the vibration measurement on the hand tractor (ISO 5349-1)**

### 2.6.3.2 Magnitude of Vibration

For practical measurements, the orientations of the coordinate system are defined with reference to an appropriate basicentric coordinate system originating in the vibrating handle gripped by the hand. The evaluation of vibration exposure in accordance to the standard ISO 5349 is based on the quantity that combines all three axes, known as vibration total value ($a_{hv}$) or weighted acceleration sum (WAS) as shown in Figure 5 and defined by the root-mean-square (R.M.S) of the three component values (Eqn. 10):

$$a_{hv} = \sqrt{(a_{hwx})^2 + (a_{hwy})^2 + (a_{hwz})^2} \quad \text{.............................} \quad (10)$$

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

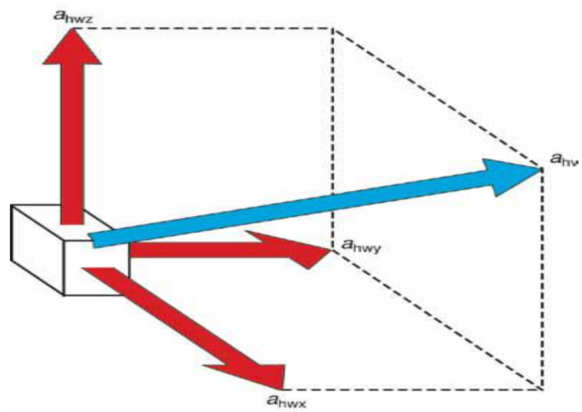



**Figure 5: The vibration total value ($a_{hv}$) (Source: Scartel *et al*., 2005)**

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)):

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \quad \text{........................................} \quad (11)$$

where; $a_{hv}$ is the vibration total value, T is the total daily duration of the exposure in s, and $T_0$ is the reference duration of 8 h (28800 s).

In annexure A of the ISO 5349-1 standard, suggests the relationship between the lifetime exposure to hand transmitted vibration; $D_y$ (years) and the 8-hour energy equivalent daily exposure A(8) for the probability to cause 10% prevalence of finger blanching and defined by:

$$D_y = 31.8[A(8)]^{-1.06} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

The ISO 5349 does not define a “safe exposure” but an informative annexure provides tentatively a quantitative exposure-response relationship for vibration-induced white finger (Table 3.1).

**Table 3.1: Latency periods for 10% prevalence of vascular disorder (ISO 5349-1:2001)**

**Frequency-weighted vibration acceleration magnitudes ($m/s^2$ rms) which may be expected to produce finger blanching in 10% of exposed persons.**

| **Dy in years** | 1 | 2 | 4 | 8 |
|---|---|---|---|---|
| **A(8) in $m/s^2$** | 26 | 14 | 7 | 3.7 |

Vibration measurement according to the ISO 5349-2 (2001), measures the vibrating surface in contact with the hand. The standard applies to periodic and random or non-periodic vibration. Provisionally, the standard may also be applied to repeated shock-type excitation. The knowledge of the effect of shock-type excitation is however limited (Burstro¨m and Sörensson, 1999).

### 2.6.4 Directive 2002/44/EC

The Directives 2002/44/EC lays down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to mechanical vibration. The Directives 2002/44/EC establishes several requirements for the protection of workers from vibration and recommends the maximum permissible vibration exposure limit for hand-arm vibration as daily exposure limit value of 5 $m/s^2$ and daily exposure action value of 2.5 $m/s^2$ standardized to an eight-hour reference period.

**Table 3.2: Proposal of the Council of European Union for a Council Directive of Physical Agents (Vibration)**

| Levels | A(8) $m/s^2$ | Definitions |
|---|---|---|
| **Threshold** | 1 | The exposure value below which continuous and/or repetitive exposure has no adverse effect on the health and safety of operators. |
| **Action** | 2.5 | The value above which one or more measures specified in the relevant annexes must be undertaken. |
| **Exposure limit Values** | 5 | The exposure value above which an unprotected person is exposed to unacceptable risks. Exceeding this level is prohibited and must be prevented through the implementation of the provisions of the Directive. |

### 2.6.5 British Standard 6842 (1987)

The British Standard 6842 (1987) offer similar guidance to ISO 5349 (1986), but is restricted to a 10% prevalence of vibration-induced white finger (Table 3.3). The procedures to quantify the magnitude of vibration total values, evaluating the daily exposure to vibration or frequency-weighted vibration total value, correspond to those applied in ISO 5349 (1986) in which 4-hour energy equivalent was used to determine frequency-weighted vibration acceleration. The standard BS 6842 (1987) gives the quantitative guidance using the prediction of 10% prevalence of exposed persons to fall on symptoms associated with vibration-induced white fingers (Finger blanching).

**Table 3.3: Latency periods for 10% prevalence of vascular disorder (BS 6842, 1987)**

**Frequency-Weighted vibration acceleration magnitudes (RMS in $m/s^2$) expected to produce finger blanching in 10% of exposed persons**

| | Life-Time Exposure | | | | | |
|---|---|---|---|---|---|---|
| Daily Exposure | 6 Months | 1 Year | 2 Years | 4 Years | 8 Years | 16 Years |
| 8 Hours | 44.8 | 22.4 | 11.2 | 5.6 | 2.8 | 1.4 |
| 4 Hours | 64 | 32 | 16 | 8 | 4 | 2 |
| 2 Hours | 89.6 | 44.8 | 22.4 | 11.2 | 5.6 | 2.8 |
| 1 Hour | 128 | 64 | 32 | 16 | 8 | 4 |
| 30 Minutes | 179.2 | 89.6 | 44.8 | 22.4 | 11.2 | 5.6 |
| 15 Minutes | 256 | 128 | 64 | 32 | 16 | 8 |

Source: British Standard BS 6842 (1987)

### 2.6.6 The ANSI S 2.70 (2006) Standard

The American National Standard Institute (ANSI S 2.70) standard specifies the use of the hand-arm vibration measurement procedure outlined in ISO 5349 (1986). It requires the measurement of ISO frequency-weighted acceleration values in three mutually orthogonal axes of vibration. These values are then vectorially added to obtain the vibration total value, $a_{hv}$ :

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

where; $a_{hwx}$ , $a_{hwy}$ , $a_{hwz}$ are frequency-weighted acceleration values in the x, y, and z directions, respectively.

When multiple vibration exposure events are experienced during a work day, the overall vibration total value is defined by:

$$a_{hv} = \left[\frac{1}{T}\sum_{i=1}^{n}\left((a_{hvi})^2 T_i\right)\right]^{1/2}$$

Where; $a_{hvi}$ is the vibration total value of the $i^{th}$ operation, $T_i$ is time duration in hours of the $i^{th}$ operation, n is the total number of operations and T is total time in hours associated with the n operations.

The daily vibration exposure value, A(8) standardized to eight-hour reference period, is obtained from Equation 11. ANSI S2.70 defines both values of A(8) equal to 2.5 $m/s^2$ as the Daily Exposure Action Value (DEAV) and A(8) equal to 5.0 $m/s^2$ as the Daily Exposure Limit Value (DELV), which represent the lower and higher health risk threshold to hand transmitted vibration respectively.

The health risk threshold is defined as the dose of hand-transmitted vibration exposure sufficient to produce abnormal signs, symptoms, and laboratory findings in the vascular, bone or joint, neurological, or muscular systems of the hands and arms in a high proportion of exposed individuals. The ANSI S2.70 standard gives guidance for vibration exposure and health risks assessments, specifies methods for mitigating health risks associated with hand-transmitted vibration, and gives guidance for operators training and medical surveillance.

### 2.6.7 American Conference of Governmental Industrial Hygienists

The American Conference of Governmental Industrial Hygienists (ACGIH) is a not-for-profit and member-based organization that stimulates workplace and environmental health by providing education and information for professionals on how to apply recommended standards. Allowable workplace exposure limits recommended by ACGIH are published each year in its booklet titled *Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices*. Table 4 presents the recommended maximum permissible occupational exposure limits for hand-arm vibration calculated using the dominant axis of the ISO 5349 (1986) guideline.

**Table 4: Threshold Limit Values**

**ACGIH Threshold Limit Values for Hand Transmitted Vibration; 2003**

| Total daily exposure duration | Maximum magnitude, $m/s^2$ (Dominant axis) | Maximum magnitude, $m/s^2$ (Approx. Vibration Total Value) |
|---|---|---|
| 4 hrs and less than 8 hrs | 4 | 5.5 |
| 2 hrs and less than 4 hrs | 6 | 8.5 |
| 1 hr and less than 2 hrs | 8 | 11 |
| less than 1 hr | 12 | 17 |

**Source:** Nelson, (2004) and http://www.ccohs.ca/oshanswers/phys_agents/vibration

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

## 3.1 Description of the Study Area

### 3.1.1 Study location

The field experiments were conducted at Kilimanjaro Agricultural Training Centre (KATC) situated at Chekereni Village, between 700 m and 1000 m above sea level and about 17 km South-East of Moshi Municipality. The village is bounded by “Rau ya Kati” village on the north, Rau river on the east, Oria Village on the south and the sugar plantation of the Tanganyika Planting Company (TPC) on the west (Fig. 6). The structured questionnaires were administered to operators found around Lower Moshi Irrigation Scheme (LMIS) in Kilimanjaro Region and Leki Tatu Irrigation Scheme in Arumeru District, Arusha Region (KATC, 2000).

### 3.1.2 Climate and topographical conditions

The climatic conditions of Chekereni Village are characterized by three seasons: a long rainy season from March to May, a dry season from June to October and a short rainy season from November to February. The study was conducted from November, 2011 to February, 2012. Weather fluctuation as were recorded by KATC meteorological station during the period of study shows that; dry bulb temperature and wet bulb temperatures were varying between 22.8–27.5$^{o}$C and 20.6-24.4$^{o}$C respectively and the relative humidity varying between 66.3–83.0%.

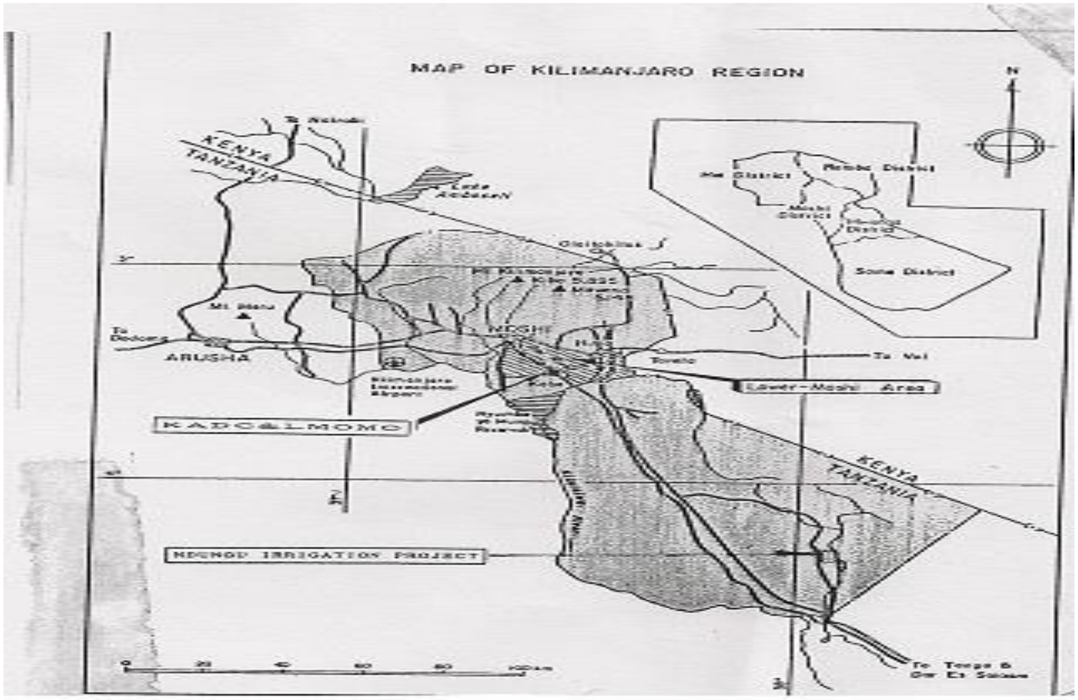



**Figure 6: Kilimanjaro Agricultural Training Centre Location map (KATC, 2000)**

### 3.1.3 Soil physical characteristics

A sample of the dark light brownish organic soils of KATC (Fig. 7) were taken to the soil and bitumen laboratory of Arusha Technical College (ATC) for classification purpose in order to obtain the general behaviour of the soil and the soil condition was assumed uniform, so that effect of the soil condition toward the machine performance is considered to be uniform in the entire field of experiment. Soil textural analysis done classified the soil of KATC as silt loam soil, with the following percentage distributions: 0.6% gravel, 13.2% sand, 83.9% silt and 2.3% clay. Average soil moisture content on dry basis in the field was 7.7%, bulk density of the soil varied from 1.54–1.73 g/cm$^3$ and the porosity of the soil was 0.44 in the entire experimental field.

**Figure 7: Soil texture of the experimental field**

## 3.2 Materials

### 3.2.1 Single-axle tractors

Single-axle tractors operating in four-stroke cycles, fitted with a horizontal single-cylinder diesel engine and water cooled was used during field experiments. The four different makes of single-axle tractors were AMEC S 1100$A_2$ (distributed by District Councils), GREAVES GS-15 DIL (supplied by SUMAJKT), KUBOTA K120 and YANMAR TF110ML (supplied by MAFC to training centres). The technical specifications for the studied single-axle tractors are shown in Table 5.

**Table 5: Technical specifications for the studied single-axle tractors**

| Engine model and type | AMEC S 1105 $A_2$ | GREAVES GS-15 DIL | KUBOTA K120 RK 125 | YANMAR YZC-D TF110ML |
|---|---|---|---|---|
| Swept volume,$cm^3$ | Not Specified | 903 | 624 | 583 |
| Rated power, kW/rpm | 12/2200 | 10.95/2000 | 9.33 / 2400 | 11.3/2400 |
| Number of Speeds | 6 Forward speeds 2 Reverse speeds | 6 Forward speeds 2 Reverse speeds | 6 Forward speeds 2 Reverse speeds | 3 Forward speeds 1 Reverse speeds |
| Rated Speed Range, km/hr | 1.54-16.83 Forward 1.21-4.18 Reverse | 1.95-16.70 Forward 1.1-4.21 Reverse | 1.11-13.93 Forward 0.91-4.36 Reverse | 1.29-8.92 Forward 0.98 Reverse |
| Speed of rotavator tines at engine speed. | Low: High: | Low: 188 High: 300 | Low: 214 High: 323 | Low: 211 S, 155L High: 377 S, 277L |
| Dry weight of engine, kg | 145 | 160 | 96 | 89.2 |
| Gross Weight of tractor kg | 495 | 515 | 353 | 316 |
| Tyre size (Pneumatic) | 6.0-12 | 6.0-12 | 6.0-12 | 5.0-12 |
| Wheel size (Steel), mm | 800 (Common) | 800 (Std) | 420-780 | 750-1000 |
| Tilling width, mm | 600 | 600 | 600 | 600 Fixed |
| Tilling speed/depth | 4 Forward speeds | First 2 speeds/150 mm | 4 Forward speeds | 2 Forward/180 mm |
| Number of tynes | 18 | 20 | 18 | 16 |
| SFC at Continuous rated output, g/HP.hr | 258 | 268 | 170 | Not Specified |

### 3.2.2 Single-axle tractor operators

The operators were selected on the basis of skills, knowledge and experience on the control and operation of single-axle tractors in varying farm conditions. The farm conditions considered were tillage with mouldboard plough (Fig. 8.1), rota-puddling (Fig.

8.2) and transportation operation (Fig. 8.3) for a minimum period of two consecutive years. Five representative operators were therefore selected to participate in the study during field experiments from the available 38 operators used by TanRice project to train farmers at KATC, Lower Moshi and Lake-Tatu Irrigation Schemes. They were healthy male operators without any physical and/or mental disorder or illness.

## 3.3 Methodology

The field reconnaissance study was undertaken for the purpose of knowing the availability of single-axle tractors and qualified operators at KATC and the farming seasons around Lower Moshi and Leki-Tatu Irrigation Schemes. In order to achieve the objectives of the study, the research study was conducted using field experiments and structured questionnaires.

Vibration magnitudes of the four different single-axle tractors were measured in the actual field conditions. The structured interviews were conducted to single-axle tractor operators using questionnaires (Appendix A) to assess their perception on the influence of mechanical shocks caused by mechanical vibration. The questionnaires covered the physical characteristics of operators, skills and experience on single-axle tractors operations, and the signs and symptoms recognized as causing occupational diseases.

### 3.3.1 Field layout and experimental conditions

The study in the field was conducted using split-split-plot experimental design (Montgomery, 1984); whereby different field conditions (operation mode) were taken as the main plot, type or make of single-axle tractors as the sub-plot and speed of operation as the sub-sub-plot. In order to increase accuracy and reduce the effects of variation in soil and environmental conditions, five randomized trials were conducted from four different single-axle tractors. The mean value of these trials was taken as the representative vibration acceleration value for a particular field condition. The operators were provided with some information on the experimental requirements so as to sensitize them and enlisting full attention and cooperation.

Single-axle tractors which priory worked for two farming seasons were serviced before conducting tests to ensure that, there were no known mechanical defects that would result in abnormal vibration. Also the servicing of the tractors was done to ensure that they were in proper working condition with full fuel tank and radiator without any optional front weights and tyre ballast to support the tractor. Pneumatic wheels with tyre pressure between 137 kPa to 196 kPa were used during tillage on dry soil and transportation operations whereas anti-skid steel wheels were used during rota-puddling operations.

The selected operators performed three operations; tilling in untilled field of paddy harvest, rota-puddling in submerged field with about 5 cm to 8 cm standing water and transportation on farm roads. The single-axle tractors were operated at three lower gear settings ($G_{1L}$, $G_{2L}$ and $G_{3L}$) for tilling and rota-puddling operations. Three higher gear settings ($G_{1H}$, $G_{2H}$ and $G_{3H}$) were used during transportation.

**Figure 8.1: Tilling operation**

**Figure 8.2: Rota-puddling operation**

**Figure 8.3: Transportation operation**

The engines were running at about 75% of the accelerator range, the average length of the plots for tilling and rota-puddling operations were 45 m. In order to have uniformity on observation time on each selected forward speed; the duration to run a field experiment were 30 minutes.

The magnitude of vibration was measured in the forward direction during each trial between two marked points at a distance of 30 m, using a hand-held vibration meter. For the purpose of the study, a representative load of approximately 500 kg comprising farm equipment and tractor attachments were loaded in trailers and attached to single-axle tractors during transportation. Operators were to control the depth of cut during tillage operation and a tailskid was used during rota-puddling operation. The depth of operation varied between 10 cm to 12 cm.

### 3.3.2 Instrumentation

A hand-held vibration meter (MTN/VM 110) conforming to the requirements of ISO 5348 (1998) and ISO 8041 (2005) were used to measure the magnitude of vibration reaching handles of single-axle tractors. A mild steel bracket was fabricated as an adapter to stabilize positioning and increase the contact area of the accelerometer. The size of the bracket was 40 *x* 35 *x* 1.0 mm, to reduce the relative vibration caused by movement of the hand-arm system and the accelerometer, a hook and a leather looping tape were used to tight the bracket firmly in the hand. The total weight of the adapter including the accelerometer, hook and loop tape was approximately 20.0 grams. The data were collected using a selectable low-pass filter accelerometer with a frequency range between 5Hz to 5 kHz and lower frequency were fixed at 5Hz. The magnitudes of the vibration obtained were recorded in a note book and analyzed at the end of the experiment.

### 3.3.3 Data collection

The adapter bracket was fixed such that the inclination of the metacarpus bone, when the hand grasped the grip; was at $45^0$ to the vertical. The vibration intensity of the hand–arm system was measured at the hand gripping the handle. Mechanical vibrations transmitted at the handle grip of the single-axle tractor were measured during each trial run. The orientation of the axes for vibration measurement was conforming to the ISO 5349 (2001a, b) recommendations. Single-axle tractor operators were interviewed using structured questionnaires with both open-type and closed-type questions (Appendix A); the data were coded and analyzed using Statistical Package for Social Science software (SPSS).

### 3.3.4 Data analysis

Microsoft excel was used for statistical analysis, interpretation and representation of the observed data. The frequency-weighted root-mean square values (rms) of vibration in three independent axes ($a_{hwx}$, $a_{hwy}$ and $a_{hwz}$) were calculated according to ISO 5349-1 (2001a) and the average root-mean square values determined for all five experimental settings. The root-mean square values were then vectorially added to determine the vibration total values, ($a_{hv}$). The vibration total values were used to determine the daily vibration exposure value A(8) to the operator in a particular working condition. The daily vibration exposure values were then used to determine or predict the vibration exposure duration in years for the onset of vascular disorder for 10% percentiles of operators exposed to hand transmitted vibration according to ISO 5349-1(2001a) (Equation (12)).

The analysis of variance (ANOVA) table was used to compare the variations within a particular vibration direction and between vibration directions. The Bonferroni test based on student's t statistics (á = 0.01) were further used for post hoc multiple comparison between the vibration magnitudes in each vibration direction. The data were coded (for open ended questions) and analyzed using Statistical Package for Social Science software (SPSS Version 16.0). The results were presented in frequency tables and given in percentages, assessing the perceptions on the influence of hand transmitted mechanical shocks to single-axle tractor operators that are recognized to cause occupational diseases associated with hand transmitted vibration.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

### 4.1 Introduction

This chapter presents and discusses the results of the study. Section (4.2) presents the results and analysis of field experiments for four single-axle tractors (Amec S 1105$A_2$, Greaves GS-15 DIL, Kubota K120 RK-125 and Yanmar YZC-D TF110ML) for tillage, rota-puddling and transportation operations. Section (4.3) discusses the results and analysis of administered questionnaire to single-axle tractor operators. Section (4.4) reports observation on the susceptibility of operators to CTS. Section (4.5) compares the field results with international guidelines and standards related to exposure of HTV.

### 4.2 Hand Transmitted Mechanical Vibration

The results presented and discussions made in this section are based on the actual field experiments done to investigate the magnitude of vibration in single-axle tractors that reaches the operator's hands. This section focuses on the vibration direction acceleration values obtained during soil tillage, rota-puddling and transportation operations; the vibration total values (vectorial sum) of the three orthogonal axes in root-mean square acceleration and the predictions of vibration exposure duration before the onset of vascular symptoms to operators according to ISO (2001b) and BS (1987). The ANSI (2006) and ACGIH (2003) limit the magnitudes of vibration in dominant axis for a given exposure period. The dominant axis is the major contributor of vibration total values among the three orthogonal axes; in which when excessive tends to induce vibration related disorders to operators that may affect their life style and impair physical strength (Griffin *et al*. 2003; Griffin and Bovenzi, 2002; Bovenzi, 2000).

### 4.2.1 Vibration direction acceleration values (m/s$^2$) during soil tillage

Table 6(1-4) presents the vibration intensities of different single-axle tractors at different vibration directions in a varying forward speeds during soil tillage. When tilling using AMEC single-axle tractor, the magnitude of acceleration in $x_h$-axis varied from 5.173 ±0.07 to 6.084 ± 0.13 m/s$^2$ which is higher than 2.149 ±0.09 to 2.543 ± 0.05 m/s$^2$ and 3.259 ± 0.08 to 4.230 ± 0.15 m/s$^2$ for the $y_h$-axis and $z_h$-axis respectively, while the forward speed varied from 1.54 to 4.51 km/hr (Table 6.1).

**Table 6.1: Vibration direction acceleration in AMEC (soil tillage)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in m/s$^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in (m/s$^2$) |
| AMEC | 1.54 | 5.173 ± 0.07 | 2.149 ± 0.09 | 3.259 ± 0.08 | 6.482 |
| | 2.75 | 5.674 ± 0.28 | 2.537 ± 0.11 | 3.810 ± 0.14 | 7.29 |
| | 4.51 | 6.084 ± 0.13 | 2.543 ± 0.05 | 4.230 ± 0.15 | 7.834 |

GREAVES single-axle tractors forward speeds varied from 1.95 to 5.70 km/hr experienced higher acceleration variation in $x_h$-axis from 6.641 ± 0.18 to 6.983 ± 0.05 m/s$^2$ compared to 2.149 ± 0.09 to 2.543 ± 0.05 and 3.259 ± 0.08 to 4.230 ± 0.15 m/s$^2$ found in $y_h$-axis and $z_h$-axis respectively (Table 6.2). Table 6.3 shows results of vibration direction acceleration obtained using KUBOTA single-axle tractor during soil tillage.

The magnitude in $x_h$-axis varied from 4.071 ± 0.62 to 5.957 ± 0.61m/s$^2$ compared to 2.243 ± 0.14 to 3.375 ± 0.16 and 2.649 ± 0.33 to 3.852 ± 0.48 of $y_h$-axis and $z_h$-axis respectively, for a speed variation from 1.11 to 2.92 km/hr.

**Table 6.2: Vibration direction acceleration in GREAVES (soil tillage)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in m/s$^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in (m/s$^2$) |
| GREAVES | 1.95 | 6.641 ± 0.18 | 2.721 ± 0.11 | 3.322 ± 0.12 | 7.908 |
| | 3.4 | 6.883 ± 0.07 | 2.839 ± 0.09 | 3.724 ± 0.41 | 8.325 |
| | 5.7 | 6.983 ± 0.05 | 3.241 ± 0.05 | 3.465 ± 0.20 | 8.442 |

Vibration intensities in YANMAR single-axle tractor (Table 6.4) were evaluated with forward speed variation of 1.04 to 7.14 km/hr showing the acceleration magnitude in $x_h$-axis varying from 4.862 ± 0.25 to 7.462 ± 0.37 which is higher than the $y_h$-axis and $z_h$-axis which were varying from 2.912 ± 0.68 to 5.578 ± 0.42 and 2.007 ± 0.22 to 4.305 ± 0.78 respectively. With YANMAR single-axle tractor it was observed that magnitude of acceleration in $y_h$-axis was noticeable than the $z_h$-axis.

**Table 6.3: Vibration direction acceleration in KUBOTA (soil tillage)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in m/s$^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in (m/s$^2$) |
| KUBOTA | 1.11 | 4.071 ± 0.62 | 2.243 ± 0.14 | 2.649 ± 0.33 | 5.35 |
| | 1.7 | 5.089 ± 0.51 | 2.500 ± 0.33 | 2.855 ± 0.03 | 6.348 |
| | 2.92 | 5.957 ± 0.61 | 3.375 ± 0.16 | 3.852 ± 0.48 | 7.856 |

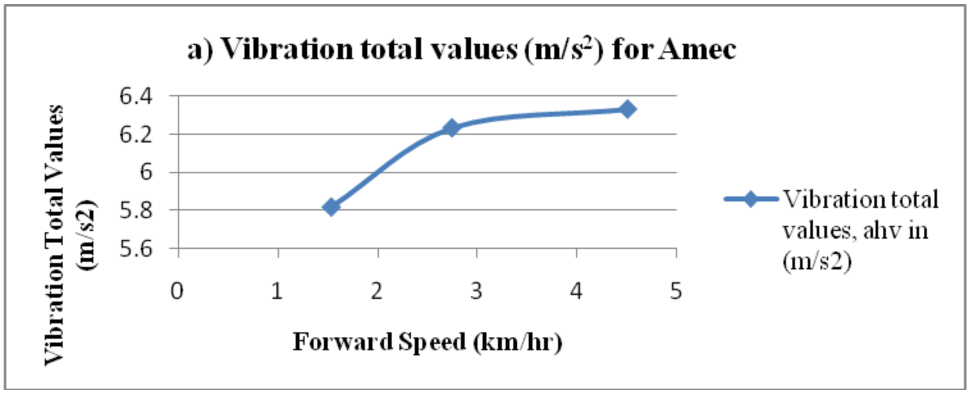
**Table 6.4: Vibration direction acceleration in YANMAR (soil tillage)**

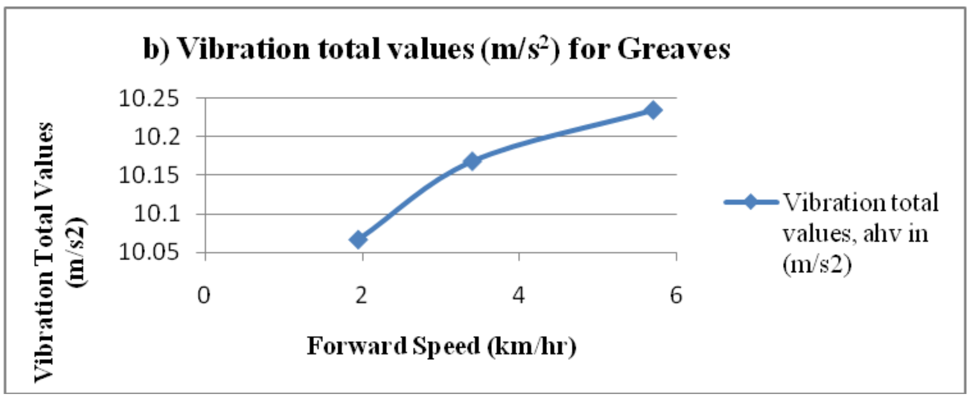
| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in m/s$^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in (m/s$^2$) |
| YANMAR | 1.04 | 4.862 ± 0.25 | 2.912 ± 0.68 | 2.007 ± 0.22 | 6.012 |
| | 2.14 | 6.116 ± 0.43 | 3.606 ± 0.35 | 2.809 ± 0.50 | 7.635 |
| | 7.14 | 7.462 ± 0.37 | 5.578 ± 0.42 | 4.305 ± 0.78 | 10.263 |

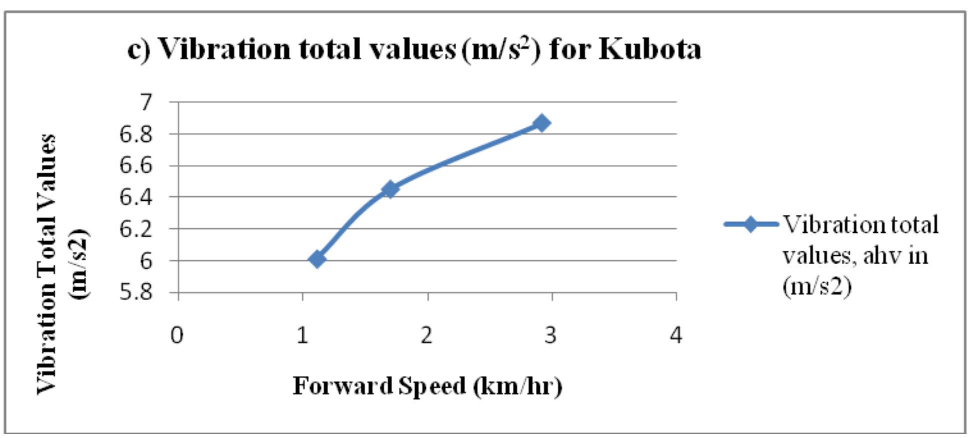
The results for AMEC single-axle tractor show that, on average the $x_h$-axis was 57% and 33% higher than $y_h$-axis and $z_h$-axis respectively. Similarly, GREAVES results show that $x_h$-axis was 57% and 49% higher than $y_h$-axis and $z_h$-axis respectively; KUBOTA shows that $x_h$-axis was 46% and 38% higher than $y_h$-axis and $z_h$-axis respectively and YANMAR results show that $x_h$-axis was 35% and 52% higher than $y_h$-axis and $z_h$-axis respectively. The high levels of vibration in tilling operation were due to cultivating on dry and compact field and the presence of paddy stalks on the surface.

It is clear from the study that the vibration acceleration (rms) in the $x_h$ direction was found to be higher than the $y_h$ and $z_h$ directions and that at any selected forward speed the vibration direction acceleration values normal to the longitudinal axis of the grip ($x_h$-axis) was the major contributor to the total vibration value. Also, it was observed that the increase in forward speed increases the vibration acceleration magnitude at almost all speed settings. Vibration acceleration on $x_h$-$y_h$-$z_h$ plane was significantly ($\alpha$ = 0.01) different throughout the experiment (Tables (9: 1-4)).

Figure 9.1(a-d) shows the relationship between vibration total values and forward speed during soil tillage and demonstrates that the increase in forward speed, leads to an increase in the vibration acceleration magnitude at almost all speed settings.



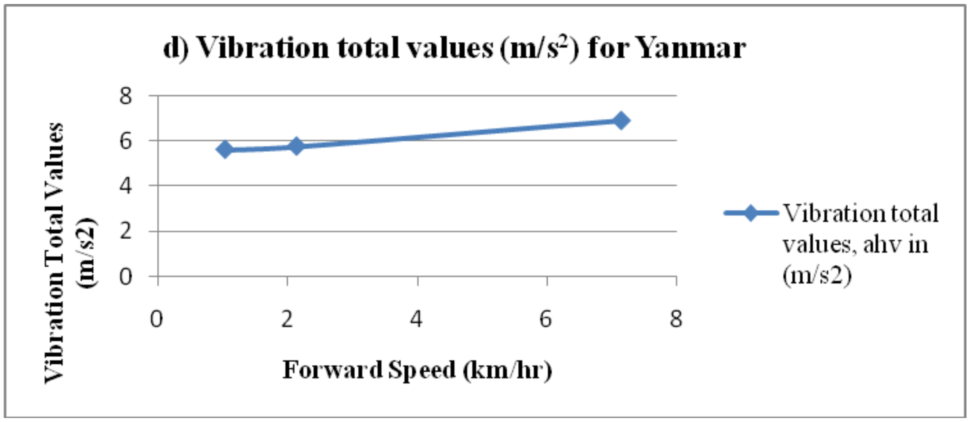



**Figure 9.1 Vibration total values versus forward speed during soil tillage**

The significant reduction in vibration magnitude along $y_h$ and $z_h$ direction were probably due to the reduction in the side movement of a single-axle tractor caused by downward force exerted by tilling attachment and the higher draft force needed. This is also supported by Chaturvedi *et al*. (In Press) who observed that, the reduction in vibration intensities along $y_h$ and $z_h$ directions is due to damping mechanism formed by interaction between tillage attachment and agricultural field soil, the exerted downward pull and requirement of higher draft force in tillage operation.

### 4.2.2 Vibration direction acceleration values in rota- puddling

Table 7.1 shows vibration direction acceleration values obtained from AMEC single-axle tractor during rotavator puddling. The magnitude of acceleration in $x_h$-axis varied from 4.940 ±0.93 to 4.579 ± 0.21 m/s$^2$, which is higher than 2.305 ±0.09 to 3.331 ± 0.11 m/s$^2$ and 2.031 ± 0.20 to 2.829 ± 0.08 m/s$^2$ for the $y_h$-axis and $z_h$-axis respectively, while the variation in forward speed was 1.54 to 4.51 km/hr.

**Table 7.1: Vibration direction acceleration in AMEC (rota-puddling)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in $m/s^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in $m/s^2$ |
| AMEC | 1.54 | 4.94 ± 0.93 | 2.305 ± 0.09 | 2.031 ± 0.20 | 5.817 |
| | 2.75 | 4.927 ± 0.22 | 2.888 ± 0.25 | 2.494 ± 0.35 | 6.232 |
| | 4.51 | 4.579 ± 0.21 | 3.331 ± 0.11 | 2.829 ± 0.08 | 6.33 |

Vibration direction intensities in GREAVES single-axle tractor (Table 7.2) were evaluated with forward speed variations of 1.95 to 5.70 km/hr and found that variation in acceleration magnitudes along $x_h$-axis were from 4.756 ± 0.52 to 5.831 ± 0.16 which is more higher than the $y_h$-axis and $z_h$-axis which varied from 2.372 ± 0.40 to 3.312 ± 0.55 and 2.855 ± 0.39 to 3.863 ± 0.39 respectively.

**Table 7.2: Vibration direction acceleration in GREAVES (rota-puddling)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in $m/s^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in $m/s^2$ |
| GREAVES | 1.95 | 4.756 ± 0.52 | 2.372 ± 0.40 | 2.855 ± 0.39 | 6.033 |
| | 3.4 | 5.409 ± 0.39 | 2.621 ± 0.38 | 3.206 ± 0.38 | 6.812 |
| | 5.7 | 5.831 ± 0.16 | 3.312 ± 0.55 | 3.863 ± 0.39 | 7.739 |

Table 7.3 presents the vibration direction acceleration values for KUBOTA single-axle tractor, the magnitude in $x_h$-axis obtained varied from 3.064 ± 0.28 to 3.249 ± 0.10 $m/s^2$ compared to 1.995 ± 0.09 to 2.041 ± 0.07 and 2.166 ± 0.14 to 2.245 ± 0.07 of $y_h$-axis and $z_h$-axis respectively, for a speed variation from 1.11 to 2.92 km/hr.

**Table 7.3: Vibration direction acceleration in KUBOTA (rota-puddling)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in $m/s^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in $m/s^2$ |
| KUBOTA | 1.11 | 3.064 ± 0.28 | 1.995 ± 0.09 | 2.166 ± 0.14 | 4.25 |
| | 1.7 | 3.457 ± 0.19 | 1.740 ± 0.16 | 2.109 ± 0.23 | 4.408 |
| | 2.92 | 3.249 ± 0.10 | 2.041 ± 0.07 | 2.245 ± 0.07 | 4.445 |

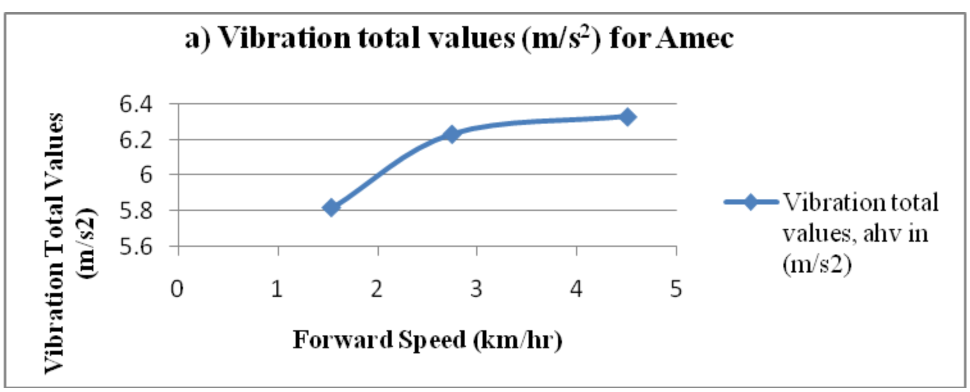
Vibration intensities in YANMAR single-axle tractor (Table 7.4) were evaluated with forward speed variation from 1.04 to 7.14 km/hr and results show that the acceleration magnitudes in $x_h$-axis vary from 4.211 ± 0.20 to 4.556 ± 0.34, which were more noticeable than the $y_h$-axis and $z_h$-axis which varied from 1.919 ± 0.08 to 2.123 ± 0.09 and 2.523 ± 0.14 to 2.482 ± 0.09 respectively. No rota-puddling data for YANMAR were collected at a forward speed of 7.14 km/hr, because at higher gears and high speeds the operators were unable to control the single-axle tractor steadily and susceptibility to injury were higher and the operation manual restricts the use of this speed to tillage and transportation operations only.

**Table 7.4: Vibration direction acceleration in YANMAR (rota-puddling)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in $m/s^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in $m/s^2$ |
| YANMAR | 1.04 | 4.211 ± 0.20 | 1.919 ± 0.08 | 2.523 ± 0.14 | 5.271 |
| | 2.14 | 4.556 ± 0.34 | 2.123 ± 0.09 | 2.482 ± 0.09 | 5.606 |
| | 7.14 | Not Recommended | | | |

The results for AMEC single-axle tractor show that, on average the $x_h$-axis was 40% and 49% higher than $y_h$-axis and $z_h$-axis respectively. Similarly, GREAVES results show that $x_h$-axis was 48% and 38% higher than $y_h$-axis and $z_h$-axis respectively; KUBOTA shows that $x_h$-axis was 41% and 30% higher than $y_h$-axis and $z_h$-axis respectively and YANMAR results show that $x_h$-axis was 54% and 43% higher than $y_h$-axis and $z_h$-axis respectively. Although the $x_h$-direction greatly influence the magnitude of vibration total values acceleration, the study observed that the magnitude of vibration acceleration during rota-puddling was much less compared to those found during tillage and transportation operations.

The study revealed that the unweighted acceleration in the direction normal to the longitudinal axis of the grip i.e. $x_h$-axis, was higher than the $y_h$-axis or $z_h$-axis respectively. At any selected forward speed the dominant and prominent contributor to the vibration total value (rms) acceleration was along $x_h$-axis. Figure 9.2 (a-d) shows that the increase in forward speed increases the vibration acceleration magnitude at almost all speed settings. Vibration acceleration on $x_h$-$y_h$-$z_h$ plane was significantly ($\alpha$ = 0.01) different throughout the experiment.



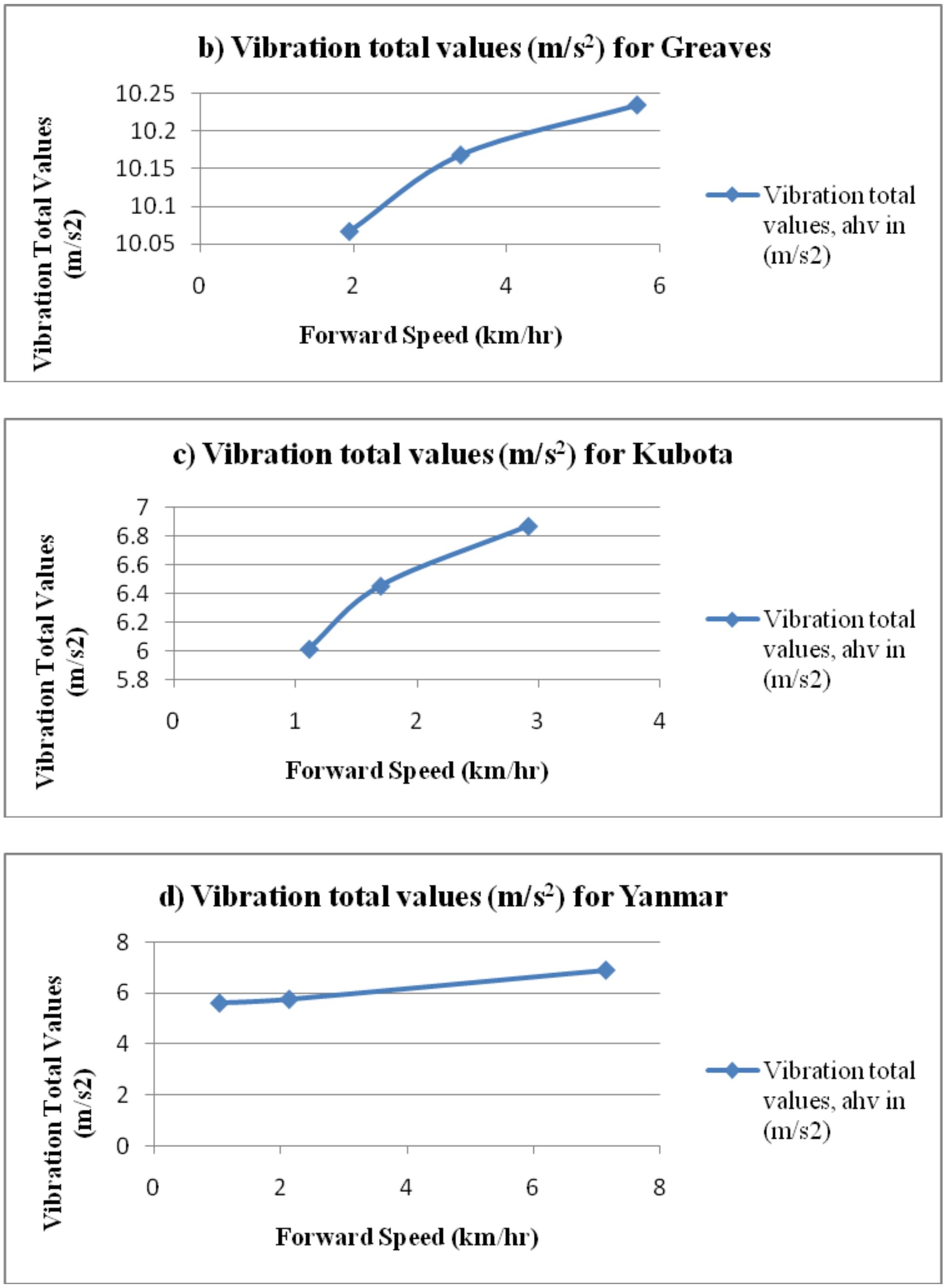



**Figure 9.2 Vibration total values versus forward speed during rota-puddling**

The significance of reduced vibration magnitude at the entire forward speed setting in rota-puddling was contributed by puddle surface (waterlogged soil condition) that act as cushion and attenuate the amount of vibration produced. Similarly, Sam and Kathirvel (2006) observed that, the effect of agricultural field condition plays great role on the vibration magnitude of single-axle tractors. It is also observed by Dewangan and Tewari (2009) that soft field surface caused lowest vibration acceleration value during rota-puddling. Further observation on lower vibrations along $y_h$- and $z_h$- directions during rota-puddling were due to integrated rotavator hitching arrangement which enable rotary power transmission to tyne to behave as single unit (Ragni *et al*. 1999; Chatuverdi *et al*. (In Press)).

Since the performance requirements of single-axle tractors are largely dependent on the machine and the human hand-arm system relationships, the study observed that rota-puddling cause's adverse effects on the stability of single-axle tractors and greater operational inconveniences to operators due to submerging tendencies in some parts of the field and energy used to lift the machine that lead to early muscular fatigue.

### 4.2.3 Vibration direction acceleration values in transportation

Table 8.1 shows the vibration direction intensities during transportation on farm roads using GREAVES single-axle tractor. The acceleration were evaluated with forward speed variation of 1.95 to 5.70 km/hr and found the acceleration magnitude in $x_h$-axis varying from 8.002 ± 0.25 to 8.731 ± 0.31 which is higher than the $y_h$-axis and $z_h$-axis which were varying from 4.514 ± 0.41 to 3.914 ± 0.13 and 4.116 ± 0.39 to 3.630 ± 0.13 respectively.

**Table 8.1: Vibration direction acceleration in GREAVES (Transportation)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in $m/s^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in $m/s^2$ |
| GREAVES | 1.95 | 8.002 ± 0.25 | 4.514 ± 0.41 | 4.116 ± 0.39 | 10.067 |
| | 3.4 | 8.417 ± 0.44 | 4.285 ± 0.20 | 3.765 ± 0.12 | 10.168 |
| | 5.7 | 8.731 ± 0.38 | 3.914 ± 0.13 | 3.630 ± 0.13 | 10.234 |

In Kubota single-axle tractor (Table 8.2), the magnitude in $x_h$-axis varied from 5.137 ± 0.94 to 5.862 ± 0.61 $m/s^2$ compared to 2.731 ± 0.29 to 2.926 ± 0.79 and 1.521 ± 0.36 to 2.070 ± 0.32 of $y_h$-axis and $z_h$-axis respectively, for a speed variation from 1.11 to 2.92 km/hr.

**Table 8.2: Vibration direction acceleration in KUBOTA (Transportation)**

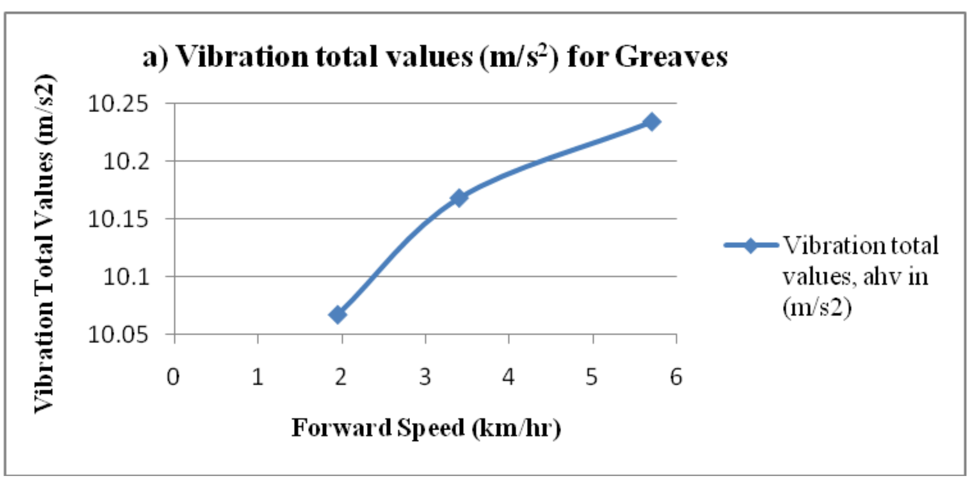
| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in $m/s^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in $m/s^2$ |
| KUBOTA | 1.11 | 5.137 ± 0.94 | 2.731 ± 0.29 | 1.521 ± 0.36 | 6.013 |
| | 1.7 | 5.817 ± 0.12 | 2.217 ± 0.15 | 1.699 ± 0.19 | 6.453 |
| | 2.92 | 5.862 ± 0.61 | 2.926 ± 0.79 | 2.070 ± 0.32 | 6.871 |

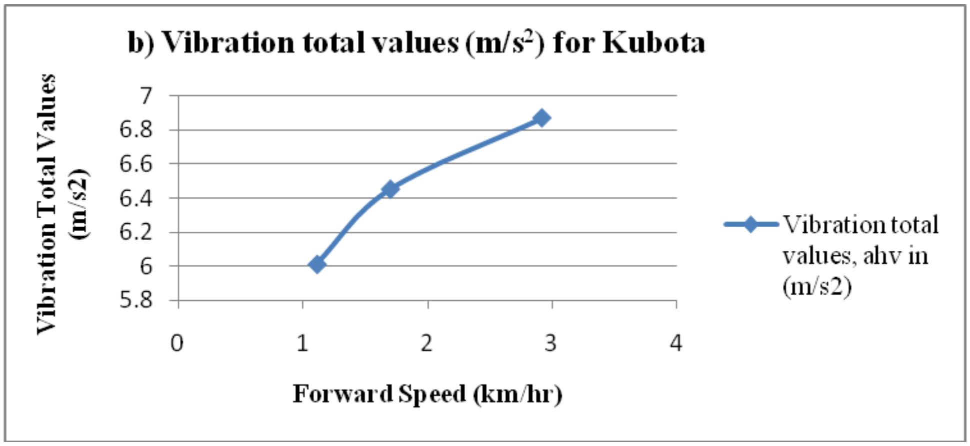
Vibration intensities in Yanmar single-axle tractor (Table 8.3) were evaluated with forward speed variation from 1.04 to 7.14 km/hr. The acceleration magnitude in $x_h$-axis were varied from 4.212 ± 0.04 to 5.604 ± 0.38 which is higher than the $y_h$-axis and $z_h$-axis which were varying from 2.808 ± 0.13 to 2.992 ± 0.19 and 2.446 ± 0.26 to 2.700 ± 0.25 respectively.

**Table 8.3: Vibration direction acceleration in YANMAR (Transportation)**

| Type of Tractor | Forward speed (km/hr) | Vibration acceleration (rms) in $m/s^2$ (Mean ± Std Deviation) | | | |
|---|---|---|---|---|---|
| | | $x_h$ | $y_h$ | $z_h$ | Vibration total values, $a_{hv}$ in $m/s^2$ |
| YANMAR | 1.04 | 4.212 ± 0.04 | 2.808 ± 0.13 | 2.446 ± 0.26 | 5.622 |
| | 2.14 | 4.371 ± 0.34 | 2.835 ± 0.32 | 2.474 ± 0.29 | 5.767 |
| | 7.14 | 5.604 ± 0.38 | 2.992 ± 0.19 | 2.700 ± 0.25 | 6.903 |

The results for GREAVES single-axle tractor show that, on average the $x_h$-axis was 49% and 54% higher than $y_h$-axis and $z_h$-axis respectively. Similarly, KUBOTA shows that $x_h$-axis was 53% and 69% higher than $y_h$-axis and $z_h$-axis respectively and YANMAR results show that $x_h$-axis was 38% and 46% higher than $y_h$-axis and $z_h$-axis respectively. Figure 9.3(a-c) shows that the increase in forward speed during transportation increases the vibration acceleration magnitude at almost all speed settings. The vibration direction acceleration in the $x_h$-direction was higher than $y_h$- and $z_h$-directions at any selected forward speed. Vibration acceleration on $x_h$-$y_h$-$z_h$ plane was significantly ($\alpha$ = 0.01) different throughout the experiment.





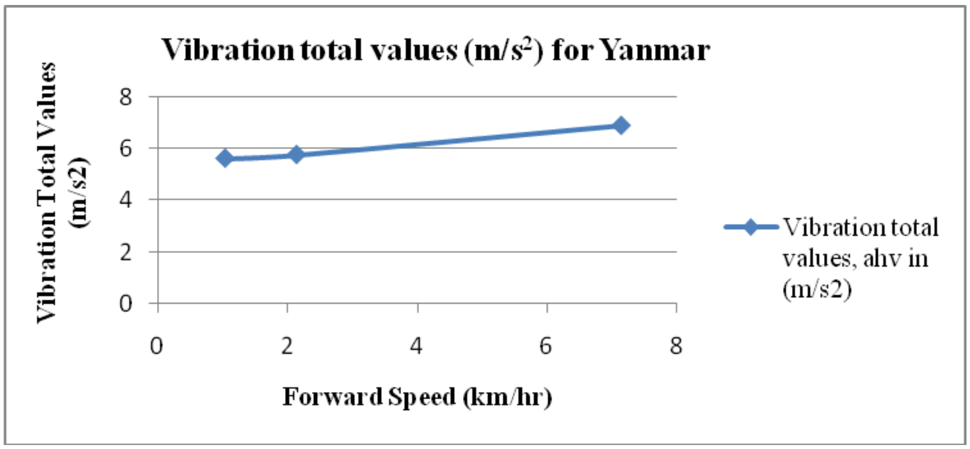




**Figure 9.3 Vibration total values versus forward speed in transportation**

Transportation operation on farm roads was observed to have higher magnitude of vibration acceleration when compared to soil tillage and rota-puddling operations. This is evident due to the assumed additional sources of vibration such as unevenness of farm roads, hauling of unbalanced loaded trailer and excessive movement of the operator. Various studies observe high magnitude of vibration acceleration during transportation operations as compared to other operations (Dewangan and Tewari, 2009; Tewari *et al*. 2004).

### 4.2.4 Vibration total values ($a_{hv}$) transmitted to the hand

The field experiment using AMEC single-axle tractor (Table 9.1) was conducted at three forward speeds 1.54, 2.75 and 4.51 km/hr for two working conditions; soil tillage and rota-puddling and the results show that, the magnitude of acceleration was 6.481, 7.290 and 7.834 m/s$^2$ for soil tillage and 5.817, 6.232 and 6.330 m/s$^2$ for rota-puddling operations respectively. No transportation data were observed during the study because of the absence of matching accessories for trailer attachment.

**Table 9.1: Vibration total value in AMEC**

| **Type of tractor** | **Operation mode** | **Forward speeds (km/hr)** | **Vibration total values, $a_{hv}$ in m/s$^2$** | **Bonferroni multiple comparison between vibration directions at α = 0.01** | | |
|---|---|---|---|---|---|---|
| | | | | $x_h$ vs $y_h$* | $x_h$ vs $z_h$* | $y_h$ vs $z_h$* |
| **AMEC** | Tillage | 1.54 | 6.482 | 3.236 | 2.092 | - 1.144 |
| | | 2.75 | 7.29 | 3.270 | 1.857 | - 1.413 |
| | | 4.51 | 7.834 | 3.683 | 1.938 | - 1.745 |
| | Rota-puddling | 1.54 | 5.817 | 1.428 | 1.872 | 0.443 |
| | | 2.75 | 6.232 | 2.266 | 2.276 | 0.020 |
| | | 4.51 | 6.33 | 2.688 | 2.972 | 0.284 |

* The mean difference is significant at the 0.01 level.

GREAVES single-axle tractor were tested at three forward speeds 1.95, 3.40 and 5.70 km/hr for three working conditions soil tillage, rota-puddling and transportation (Table 9.2) and observed the following magnitudes of acceleration; 7.908, 8.325, and 8.442 m/s$^2$ for soil tillage; 6.033, 6.812 and 7.739 m/s$^2$ for rota-puddling operation and 10.067, 10.168 and 10.234 m/s$^2$ for transportation in untarmaced farm road respectively.

The weighted acceleration sum for KUBOTA single-axle tractor (Table 9.3) were obtained from three forward speeds 1.11, 1.70 and 2.92 km/hr for three working conditions; soil tillage, rota-puddling and transportation. The vibration total value were respectively represented as 5.350, 6.348 and 7.856 $m/s^2$ for soil tillage, 4.250, 4.408 and 4.445 $m/s^2$ for rota-puddling and 6.013, 6.453 and 6.871 $m/s^2$ for transportation on farm road. YANMAR single-axle tractor operating at 1.04, 2.14 and 7.14 km/hr forward speeds, respectively gave the following root-mean square values in three agricultural setting; 6.012, 7.635 and 10.263 for soil cultivation with mouldboard plough, 5.271 and 5.606 $m/s^2$ for rota-puddling and 5.622, 5.767 and 6.903 $m/s^2$ for transportation on uneven terrain of the farm road (Table 9.4).

**Table 9.2: Vibration total value in GREAVES**

| **Type of tractor** | **Operation mode** | **Forward speeds (km/hr)** | **Vibration total values, $a_{hv}$ in $m/s^2$** | **Bonferroni multiple comparison between vibration directions at α = 0.01** | | |
|---|---|---|---|---|---|---|
| | | | | $x_h$ vs $y_h$* | $x_h$ vs $z_h$* | $y_h$ vs $z_h$* |
| **GREAVES** | Tillage | 1.95 | 7.908 | 4.002 | 3.355 | 0.443 |
| | | 3.4 | 8.325 | 4.130 | 3.110 | - 1.030 |
| | | 5.7 | 8.442 | 3.659 | 3.394 | - 0.275 |
| | Rota-puddling | 1.95 | 6.033 | 2.296 | 1.962 | - 0.334 |
| | | 3.4 | 6.812 | 3.071 | 2.354 | - 0.716 |
| | | 5.7 | 7.739 | 3.051 | 2.374 | -0.677 |
| | Transportation | 1.95 | 10.067 | 3.757 | 3.983 | 0.226 |
| | | 3.4 | 10.168 | 3.875 | 4.356 | 0.481 |
| | | 5.7 | 10.234 | 4.444 | 4.817 | 0.373 |

* The mean difference is significant at the 0.01 level.

It has been shown experimentally in the results Table 9(1-4) that, with the same field setting and exposure time throughout the experiment; a significant variation results into the vibration total values transmitted to the hand between different make of single-axle tractors and operators at any forward speed, the difference may either be characterized by biodynamic or individual factors. The biodynamic factors includes the coupling between human hand-arm and the machine handle and hand posture during operation or individual factors such as operator's tractor control, tractor's work rate, individual susceptibility to vibration, and exposure to other physical agents, skill and productivity contribute significantly on variation of vibration exposure among operators at various field operations and forward speeds.

**Table 9.3: Vibration total value in KUBOTA**

| **Type of tractor** | **Operation mode** | **Forward speeds (km/hr)** | **Vibration total values, $a_{hv}$ in m/s$^2$** | **Bonferroni multiple comparison between vibration directions at α = 0.01** | | |
|---|---|---|---|---|---|---|
| | | | | $x_h$ vs $y_h$* | $x_h$ vs $z_h$* | $y_h$ vs $z_h$* |
| **KUBOTA** | Tillage | 1.11 | 5.35 | 1.756 | 1.373 | - 0.383 |
| | | 1.7 | 6.348 | 2.629 | 1.933 | - 0.697 |
| | | 2.92 | 7.856 | 2.531 | 2.040 | - 0.491 |
| | Rota-Puddling | 1.11 | 4.25 | 1.422 | 1.099 | - 0.334 |
| | | 1.7 | 4.408 | 1.246 | 1.089 | - 0.157 |
| | | 2.92 | 4.445 | 1.422 | 1.246 | - 0.177 |
| | Transportation | 1.11 | 6.013 | 2.060 | 2.963 | 0.912 |
| | | 1.7 | 6.453 | 3.071 | 4.326 | 1.265 |
| | | 2.92 | 6.871 | 3.983 | 4.464 | 0.481 |

* The mean difference is significant at the 0.01 level.

The study demonstrates that operators of single-axle tractors experience considerable performance impairment which can be harmful to their health after daylong operations. Similarly, it was observed that the way operators apply pushing force or pulling force at the single-axle tractor handles in order to manoeuvre at headlands contribute much in amplification of vibration magnitude transmitted to the hand. The study further observes that, there is a significant variation in hand-transmitted vibration due to change in forward speed of operation. Similar observations were also reported by Sam and Kathirvel (2006).

**Table 9.4: Vibration total value in YANMAR**

| Type of tractor | Operation mode | Forward speeds (km/hr) | Vibration total values, $a_{hv}$ in $m/s^2$ | Bonferroni multiple comparison between vibration directions at α = 0.01 | | |
|---|---|---|---|---|---|---|
| | | | | $x_h$ vs $y_h$* | $x_h$ vs $z_h$* | $y_h$ vs $z_h$* |
| YANMAR | Tillage | 1.04 | 6.012 | 2.040 | 2.874 | 0.824 |
| | | 2.14 | 7.635 | 2.502 | 3.267 | 0.765 |
| | | 7.14 | 10.263 | 1.952 | 3.267 | 1.315 |
| | Rota-puddling | 1.04 | 5.271 | 2.276 | 1.638 | - 0.638 |
| | | 2.14 | 5.606 | 2.502 | 2.139 | - 0.373 |
| | | 7.14 | Not Recommended | | | |
| | Transportation | 1.04 | 5.622 | 1.334 | 1.736 | 0.402 |
| | | 2.14 | 5.767 | 1.589 | 2.011 | 0.422 |
| | | 7.14 | 6.903 | 2.629 | 2.923 | 0.304 |

* The mean difference is significant at the 0.01 level.

The study observes that, the coupling between operators hand and the bare handle of single-axle tractor transmits excessive vibration to the body; as the operator’s hand acts as a cushion to vibration. Therefore, long exposure to high vibration magnitudes subjects single-axle tractor operators to susceptible physiological or psychological fatigue. Welcome *et al*. 2004; Griffin, 1996; Radwin *et al*. 1987; Cannon *et al*. 1981; Reynolds and Soedel, 1972 reported similarly observation that, the magnitude of the grip force and or push force applied by the operator on a vibrating tool handle affects the severity of exposure to hand transmitted vibration.

### 4.2.5 Vibration exposure duration

It is evident from the study results that there are significant differences in vibration total values between tilling, rota-puddling and transportation operations, which amount to the variation on the prediction of lifetime exposure to hand transmitted vibration for the appearance of VWF in 10% of single-axle tractor operators. In practice, working at a single operational mode on agricultural field may involve the use of different forward speeds, therefore the average latency period was assumed to represent each operation.

**Table 10.1: Latency period for 10% prevalence of vascular disorder in AMEC**

| Type of tractor | Operation mode | Forward speeds (km/hr) | Latent period, years |
|---|---|---|---|
| **AMEC** | Tillage | 1.54 | 4.39 |
| | | 2.75 | 3.87 |
| | | 4.51 | 3.59 |
| | Rota-puddling | 1.54 | 4.92 |
| | | 2.75 | 4.57 |
| | | 4.51 | 4.50 |

Latency period for the appearance of vibration-induced white finger among the operator's of the AMEC single-axle tractor is shown in Table 10.1. During soil tillage, the maximum values of total vibration varied from 6.482 to 7.834 $m/s^2$ and 5.817 to 6.330 $m/s^2$ during rota-puddling. The predicted exposure duration (years) for 10% operators to show symptoms of vibration-induced disorders were observed to be 4.39, 3.87 and 3.59

years, if they operate single-axle tractor at full load for 8 hours per day during soil tillage at 1.54, 2.75 and 4.51 km/hr, respectively. Similarly the onset of symptom of vibration-induced white finger for 10% of the exposed population was 4.92, 4.57 and 4.50 years during rota-puddling at 1.54, 2.75 and 4.51 km/hr, respectively. On average, the results predict that the latency period for the onset of vibration-induced white finger for all operation modes is 4 years for AMEC single-axle tractor (Fig. 10.1).

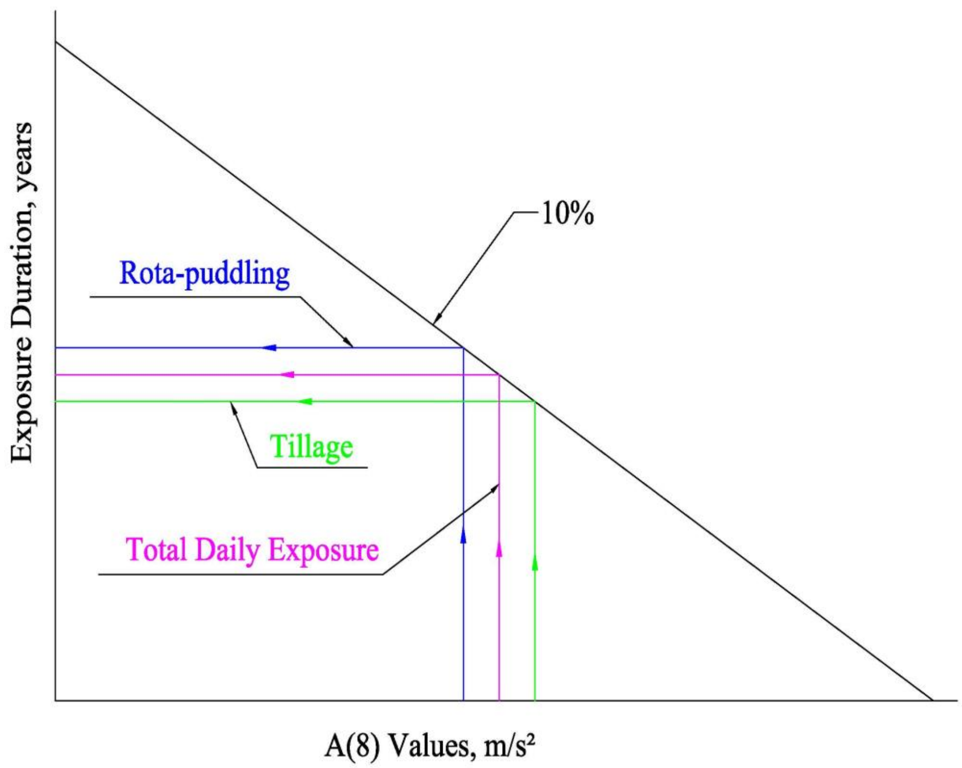


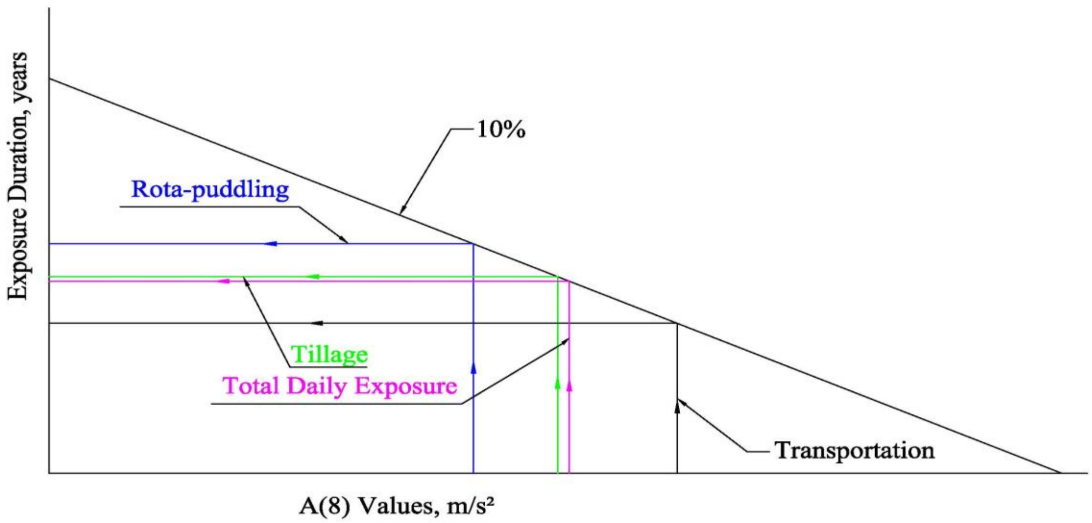

**Figure 10.1: Latency period for symptoms of vascular disorder in AMEC**

The total vibration intensity experienced in GREAVES single-axle tractor in soil tillage varied from 7.908 to 8.442 m/s$^2$, in rota-puddling varying from 6.033 to 7.739 m/s$^2$ and 10.067 to 10.234 m/s$^2$ during transportation. The corresponding value of probable exposure limit (years) for the onset of vibration-induced disorder for 10% of operators were found to be 3.55, 3.36 and 3.31 years, if they operate for 8 h per day during soil tillage at 1.95, 3.40 and 5.70 km/hr, respectively. Similarly the onset of symptom of vibration-induced white finger for 10% of the exposed operators was 4.73, 4.02 and 3.74 years during rota-puddling and 2.73, 2.72 and 2.71 years during transportation at 1.95, 3.40 and 5.70 km/hr, respectively (Table 10.2).

**Table 10.2: Latency period for 10% prevalence of vascular disorder in GREAVES**

| Type of tractor | Operation mode | Forward speeds (km/hr) | Latent period, years |
|---|---|---|---|
| **GREAVES** | Tillage | 1.95 | 3.55 |
| | | 3.40 | 3.36 |
| | | 5.70 | 3.31 |
| | Rota-Puddling | 1.95 | 4.73 |
| | | 3.40 | 4.02 |
| | | 5.70 | 3.74 |
| | Transportation | 1.95 | 2.73 |
| | | 3.40 | 2.72 |
| | | 5.70 | 2.71 |

On average the results predicts that the latency period for the onset of vibration-induced white finger for all operation modes is less than 4 years for GREAVES single-axle tractor (Fig. 10.2).




**Fi**

**gure 10.2: Latency period for symptoms of vascular disorder in GREAVES**

Table 10.3 shows the predicted exposure duration (years) for the onset of vibration-induced disorders in KUBOTA single-axle tractor. If they operate for 8 hours per day during soil tillage at 1.11, 1.70 and 2.92 km/hr, the onset are expected after 5.37, 4.48 and 3.58 years respectively.

**Table 10.3: Latency period for 10% prevalence of vascular disorder in KUBOTA**

| Type of tractor | Operation mode | Forward speeds (km/hr) | Latent priod, years |
|---|---|---|---|
| **KUBOTA** | Tillage | 1.11 | 5.37 |
| | | 1.7 | 4.48 |
| | | 2.92 | 3.58 |
| | Rota-puddling | 1.11 | 6.86 |
| | | 1.7 | 6.60 |
| | | 2.92 | 6.54 |
| | Transportation | 1.11 | 4.75 |
| | | 1.7 | 4.41 |
| | | 2.92 | 4.12 |

Similarly the onset of symptom of vibration-induced white finger for 10% of the exposed population was 6.86, 6.60 and 6.54 years during rota-puddling and 4.75, 4.41 and 4.12 years at 1.11, 1.70 and 2.92 km/hr, respectively. The latency period is 6 years for KUBOTA single-axle tractors (Fig.10.3). The first three running speeds either at low or high were recommended by manufacturer as suitable to most agricultural field settings and therefore were used during farm field experiments.

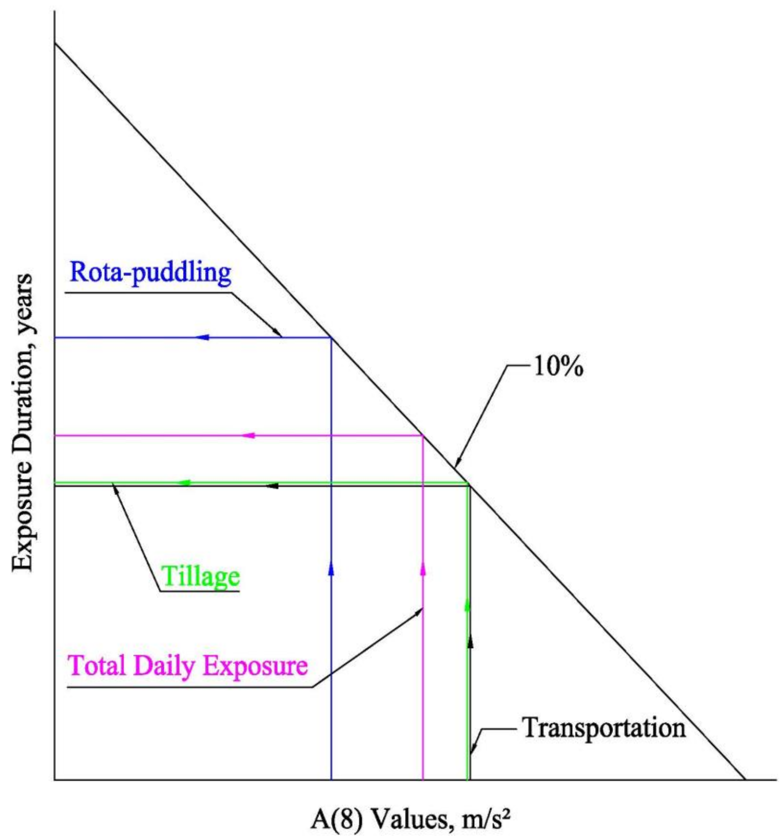



**Figure 10.3: Latency period for symptoms of vascular disorder in KUBOTA**

The maximum intensities of vibration in YANMAR single-axle tractor varied from 6.012 to 10.263 m/s$^2$ in tillage, 5.271 to 5.606 m/s$^2$ in rota-puddling and 5.622 to 6.903 m/s$^2$ in transportation. Table 10.4 shows the probability that 10% of the total operators falling victims to vibration white-finger syndrome (years) are expected after 4.75, 3.69 and 2.70 years for 8 hours operation per day during soil tillage at 1.04, 2.14 and 7.14 km/hr, respectively. Similarly, the onset of symptom of vibration-induced white finger for 10% of the total exposed operators was 5.46 and 5.12 years during rota-puddling and 5.10, 4.96 and 4.10 years during transportation at 1.04, 2.14 and 7.14 km/hr, respectively. The latency period is less than 5 years for YANMAR (Fig. 10.4).

**Table 10.4: Latency period for 10% prevalence of vascular disorder in YANMAR**

| Type of tractor | Operation mode | Forward speeds (km/hr) | Latent period, years |
|---|---|---|---|
| **YANMAR** | Tillage | 1.04 | 4.75 |
| | | 2.14 | 3.69 |
| | | 7.14 | 2.70 |
| | Rota-Puddling | 1.04 | 5.46 |
| | | 2.14 | 5.12 |
| | | 7.14 | Not Recommended |
| | Transportation | 1.04 | 5.10 |
| | | 2.14 | 4.96 |
| | | 7.14 | 4.10 |

The differences in vibration total values and the prediction of the onset of symptoms for vibration-induced disorders between tilling, rota-puddling and transportation operations are largely influenced by the physical, biodynamic and individual factors. These necessitates the importance of further research on vibration exposure transmitted through hand and justifiable factors that actually play a great role on the occurrence of HAVS among single-axle tractor operators in Tanzania. Griffin *et al*. (2003) recommend that better predictions of vibration-induced disorders can be obtained by using vibration direction acceleration values in the dominant axis rather than the currently recommended vibration total values.

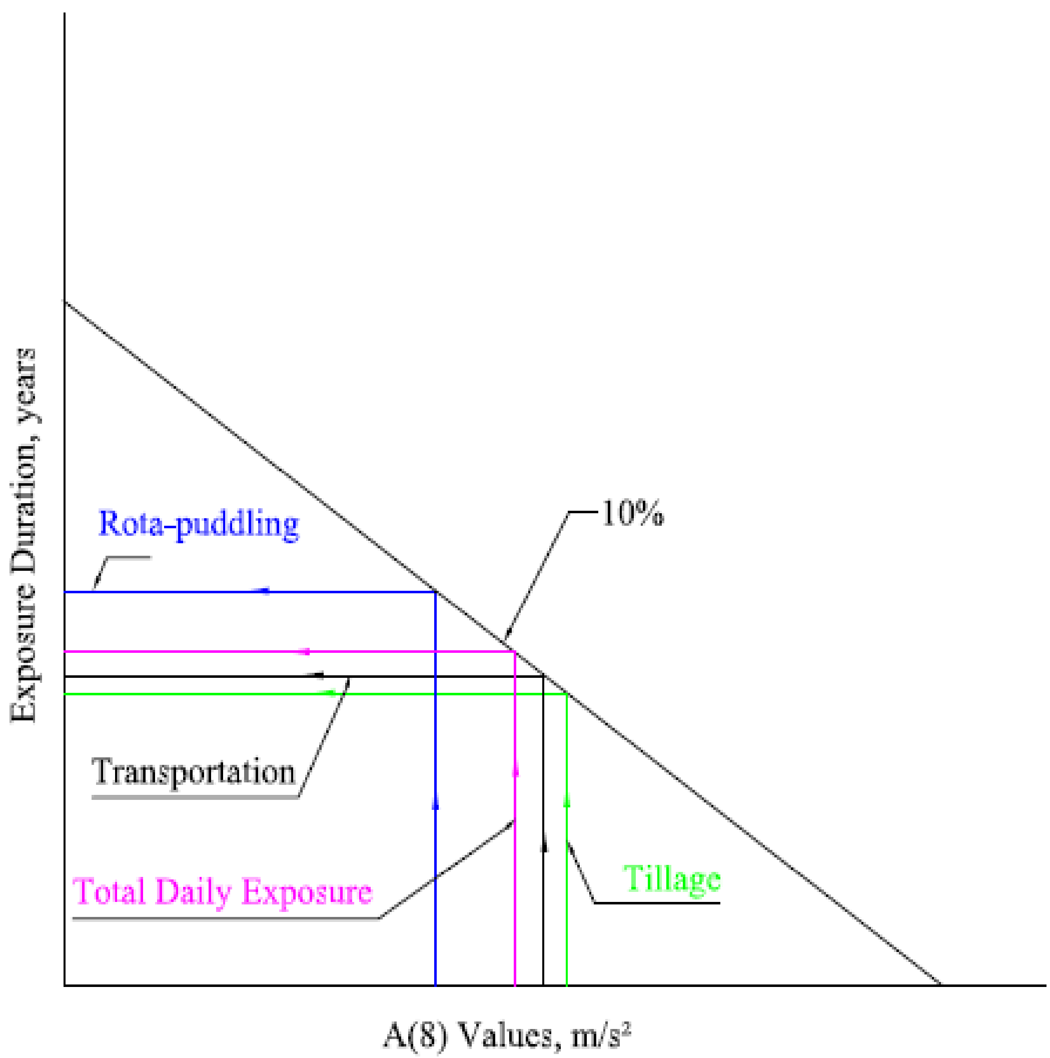



**Figure 10.4 Latency period for symptoms of vascular disorder in YANMAR**

## 4.3 Physical characteristics of single-axle tractor operators

### 4.3.1 Operator's profile

Basic physical characteristics of the single-axle tractor operators who participated in the field experiment are presented in Table 11. The mean age, stature and weight together with their respective standard deviations were respectively, 33.2 ± 4.4 years, 170.6 ± 5.4 cm and 62.0 ± 6.8 kg.

**Table 11: Physical characteristics of single-axle tractors operators**

| **Subject No.** | **1** | **2** | **3** | **4** | **5** | **Mean** | **Standard deviation** | **Coefficient of variation** |
|---|---|---|---|---|---|---|---|---|
| **Age (yrs)** | 41 | 31 | 35 | 30 | 29 | 33.2 | 4.4 | 13 |
| **Height (cm)** | 166 | 168 | 173 | 166 | 180 | 170.6 | 5.4 | 3.2 |
| **Weight (kg)** | 66 | 50 | 68 | 59 | 67 | 62 | 6.8 | 11 |

The average age, stature and weight of the 38 interviewed male operators were respectively, 28.6 ± 5.7 years, 170 ± 5.9 cm and 57.8 ± 12.6 kg as illustrated in Tables 12, 13 and 14.

**Table 12: Age of respondents by percentage (N = 38)**

| Age of respondent | Number of operators | Percentage |
|---|---|---|
| 18-22 Years | 6 | 15.8 |
| 23-27 Years | 11 | 28.9 |
| 28-32 Years | 13 | 34.2 |
| 33-37 Years | 6 | 15.8 |
| 38-42 Years | 2 | 5.3 |

The study observed that single-axle tractor operations in the studied area are dominated by male operators. Human anthropometrics (hand and arm sizes) are important individual factors that determine the dynamic properties of the hand-arm system as reported by Burstro¨m (1997). The workplace design of male dominated occupations become less comfortable for female because of the force capabilities and male dimensions considered in its design.

**Table 13: Height of respondents (N = 38)**

| Height | Number of operators | Percentage |
|---|---|---|
| 158-162 cm | 6 | 15.8 |
| 163-167 cm | 6 | 15.8 |
| 168-172 cm | 12 | 31.6 |
| 173-177 cm | 8 | 21.1 |
| 178-182 cm | 6 | 15.8 |

Traditionally, male workers dominate many occupations having salient work activities that involve the use of muscular energy to support tools, machineries or subjected to exposure of unfavourable work environment.

**Table 14: Weight of respondents (N = 38)**

| Weight | Number of operators | Percentage |
|---|---|---|
| 44-52 kg | 10 | 26.3 |
| 53-61 kg | 13 | 34.2 |
| 62-70 kg | 12 | 31.6 |
| 71-79 kg | 1 | 2.6 |

**Table 14: Weight of respondents (N = 38)**

| | | |
|---|---|---|
| 80-88 kg | 2 | 5.3 |

The anthropometric variations among operators plays great role on the use of physical efforts required to operate single-axle tractors, the amount of perceived weakness of the body after daylong operation and the interaction between the machine and human hand-arm system. As Dong *et al*. (2005) observe, individual differences manifest diverse mechanical properties in the tissues and joints and the biodynamic response is relatively sensitive to these variations.

In Tanzania, it is estimated that more than 56% of workers involving in agricultural activities are female and young workers (URT, 2009a). Dutta *et al*. 1994 observed that the anthropometric design of tools and work places was found to be the major cause of higher prevalence of work-related diseases to females. ILO recommends that the susceptibility of young workers to musculoskeletal injury is higher due to musculature development and soft bone density (ILO, 2010). Therefore, there is a need to restrict or discourage child labour (less than 18 years) from intensive work settings such as operations of single-axle tractors in agriculture.

**Table 15: Respondent's dominant hand(s) (N = 38)**

| Dominant Hand | Number of operators | Percentage |
|---|---|---|
| Left | 7 | 18.4 |
| Right | 29 | 76.3 |
| Both | 2 | 5.3 |

Table 15 shows that 76.3% of the operators were dominant in the right hand, 18.4% dominant in the left hand and 5.3% were dominant in both hands in which case measurement were taken to the hand of their choice.

Skills of an operator influence the general understanding of the principles that govern occupational safety of single-axle tractor operations. The study found that the education level of the interviewed operators ranges from secondary education (10.5%), primary education (86.8%) and to those who had not gone to school (2.6%) as indicated in Table 16. The study observes that majority of single-axle operators are educated; therefore, they can easily learn and understand the basic principles of single-axle tractor operations that govern occupational safety and health. The study found further that, the majority of single-axle tractor operators obtain there operational skills through on job training (Table 22) and lack the basics of single-axle tractor handling while working such as; the area of contact with vibrating handle, amount of applied grip or push force, and how best the interaction between hand-arm and machine handle can be established for safe operation. Similar observations were also reported by Brammer (2008) and Griffin (1997).

**Table 16: Levels of education attained (N = 38)**

| Education level | Number of operators | Percentage |
|---|---|---|
| Primary education | 33 | 86.8 |
| Secondary Education | 4 | 10.5 |
| Not Gone to School | 1 | 2.6 |

Operator's experience on some of the influencing factors such as hand-arm postures and application of the required gripping force or pressure to single-axle tractor handles are important. These factors contribute much to the effects of physical response of the hand-arm system in relation to the transmitted mechanical vibration through operator's hand. Similar observation was also reported by Griffin (1996).

Table 17 shows the operator's dependence on single-axle tractors operation. The result shows that 92% of the interviewed operators are employed as single-axle tractor operators. They depend on single-axle tractor operations to earn living and up keep of their families. Great dependencies of operators to single-axle tractor operations necessitate special effort to impart the necessary techniques, skills and general understanding of single-axle tractor operations. This is true due to the fact that, safe working conditions can be established when the procedures and safety precautions are well understood and kept in mind during operations. These can be effectively done through formal training in agricultural centres or demonstrations in farmer field schools.

**Table 17: Employment (N = 38)**

| Employed as Power Tiller Operator? | Number of operators | Percentage |
|---|---|---|
| Yes | 35 | 92 |
| No | 3 | 8 |

Smoking tendency are seen to contribute to finger blanching for some occupations, Table 18 shows that 39.5% of the operators were regular smokers and 60.5% were non-smokers. However, among regular smokers 23.7% presumably agreed that smoking was helpful to their career as they stimulate and activate their bodies towards the effects of direct sun radiation and 13.2% reported to smoke for leisure and the remaining 2.6%

were unable to classify helpfulness of smoking behaviour to their career as per results shown in Table 19.

**Table 18: Smoking habit of operators (N = 38)**

| Smoked for a month or longer? | Number of operators | Percentage |
|---|---|---|
| Yes | 15 | 39.5 |
| No | 23 | 60.5 |

However, Griffin *et al*. (2003); Griffin, (1997) found that there is no direct relationship between the development of finger blanching or vibration-induced disorders as occupational related injuries and smoking habit of an operator.

**Table 19: Smoking helpful to the career (N = 38)**

| Smoking helpful? | Number of operators | Percentage |
|---|---|---|
| No | 23 | 60.5 |
| Yes | 9 | 23.7 |
| Smoke for Leisure | 5 | 13.2 |
| Do not understand | 1 | 2.6 |

In their spare time (after normal working hours), majority of the operators (97.4%) were not involved in the operations of other vibrating hand-held machine tools or equipments (Table 20).

**Table 20: Working with other hand-held vibrating tools (N = 38)**

| Other hand-held vibrating tools? | Number of operators | Percentage |
|---|---|---|

**Table 20: Working with other hand-held vibrating tools (N = 38)**

| | | |
|---|---|---|
| Yes | 1 | 2.6 |
| No | 37 | 97.4 |

### 4.3.2 Operator training and experience on single-axle tractor operations

In Table 21, 26.3% of the total operators report having prior training on single-axle tractor operations obtained from different training modes (either formal or informal) such as on the job training before practicing in the field and 73.7% reported not having prior skills on the basics of single-axle tractor operations.

**Table 21: Prior training on how to operate power tiller (N = 38)**

| Do you have prior training? | Number of operators | Percentage |
|---|---|---|
| Yes | 10 | 26.3 |
| No | 28 | 73.7 |

Farmers realize the contribution of single-axle tractor to family economy; particularly in the fields of paddy rice production. Proper training of single-axle tractor operators will reduce the possibility of accident that can cause injuries and therefore reduce the downtime period for production activities. The study demonstrates that only 26.3% of the total operators had prior skills on the principles governing single-axle tractor operation.

The study shows that 21% of the total operators attended residential training courses conducted in collaboration between KATC and Tanzania Rice Project (TanRice), 15.9%

were trained through field practices conducted by agro-mechanics at ward level, 2.6% were trained by single-axle tractor suppliers and 60.5% obtained their operation skills in the field by working as assistant to operators (on the job training) (Table 22). The study found that operators under on job training obtain very minimum basics of single-axle tractor operation techniques to facilitate day to day activities on the farm and therefore stakeholders support is needed to conduct proper training widely in the country to make farm equipments and machineries safe, reliable and productive.

As in Table 22; 60.5% of operators rely on the job training that is seen to impart the minimum of basic techniques of single-axle tractor operation. ILO describes agriculture as the most hazardous of all sectors, and agricultural workers suffer the most from occupational accidents and ill-health each year (ILO, 2010); these necessitates clear understanding of the handling and operation principles of farm machinery .

**Table 22: Training of power tiller operator (N = 38)**

| Training Attended | Number of operators | Percentage |
|---|---|---|
| KATC | 8 | 21.1 |
| Tractor Supplier's | 1 | 2.6 |
| Training by Trained Operator | 6 | 15.8 |
| On the Job Training | 23 | 60.5 |

Safety and health regulations at workplaces are only beginning to be developed in Tanzania; therefore highlighting the actual field environment of single-axle tractor promotes awareness of the associated hazards and health risks.

**Table 23: Hardship experienced on first days (N = 38)**

| Hardship experienced | Number of operators | Percentage |
|---|---|---|
| Body Pain | 10 | 26.3 |
| Tiredness | 11 | 28.9 |
| Body pain and Tiredness | 17 | 44.7 |

Operators had different opinions on the hardships experienced on first month of intensive field activities. Twenty six percent (26.3%) of the operators felt muscular body pain, 28.9% felt tiredness, and 44.8% felt a combination of both muscular body pain and tiredness as illustrated in Table 23. The operator's were in opinion that among the contributors to such ill-health conditions felt during operation were due to extreme direct sun radiation, excessive noise and vibration, lifting heavy weights and dusty or non-conducive environment. In practice, operators of single-axle tractors work for more than eight hours during peak season of seedbed preparation as illustrated in Table 24.

**Table 24: Operating hours during farming season (N = 38)**

| Operating hours | Number of operators | Percentage |
|---|---|---|
| 7-9 hrs | 5 | 13.2 |
| 10-12 hrs | 27 | 71.0 |
| 13-15 hrs | 3 | 7.9 |
| 16-18 hrs | 3 | 7.9 |

In normal agricultural environment single-axle tractor operators need to balance the forces generated by their own bodies (generated within muscles, tendons and ligaments) in response to the externally opposing forces and that required to control the single-axle tractor at uncomfortable posture that subject the operator to various susceptible injuries. As NIOSH (1997) observes, work related injuries include external forces to the operator's hand-arm system, repetition and awkward body postures.

Table 25 shows the experiences of operators involved in the study where the mean years of operation and standard deviation were 7.2 ± 3.50 years. Although the result shows that 55% of single-axle tractor operators have experiences between 7 to 15 years; only the 45% of the operators participates on day to day farm activities. The most experienced operators are engaged on training junior operators and servicing of single-axle tractors on farm workshops.

**Table 25: Experience in operating single-axle tractor (N = 38)**

| Experience | Number of operators | Percentage |
|---|---|---|
| 1-3 yrs | 4 | 10.5 |
| 4-6 yrs | 13 | 34.2 |
| 7-9 yrs | 10 | 26.3 |
| 10-12 yrs | 7 | 18.4 |
| 13-15 yrs | 4 | 10.5 |

Table 26 shows the prediction of when the required pressure in handle gripping is reached; 31.6% predicted that the required gripping force is reached when applying normal pressure to grip the handle (holding handle as when riding bicycle), 55.3% when operator feels a shaking object in hand, 2.6% when an operator is pulled and feels shaking object and 10.5% were not able to predict the correct handle gripping pressure.

**Table 26: Prediction of required pressure to grip the handle (N = 38)**

| Correct handle gripping | Number of operators | Percentage |
|---|---|---|
| Sensing a Hand Shake | 21 | 55.3 |
| Pulling and Hand shake | 1 | 2.6 |
| Normal handle grip | 12 | 31.6 |
| Do not know | 4 | 10.5 |

Operators had different opinions on the working conditions which are considered difficult when operating single-axle tractors. Forty two percent (42.1%) of the total operators reported tilling with mouldboard plough as difficult operation, 44.7% reported rota-puddling as a difficult operation, 10.5% considered transportation operation as difficult, and 2.6% considered operating single-axle tractors in the three working conditions as difficult (Table 27). To describe the working condition as difficult, operators gave reasons as indicated in Table 28.

**Table 27: Difficult working condition to operate power tiller**

| Working conditions | Number of operators | Percentage |
|---|---|---|
| Tillage | 16 | 42.1 |
| Puddling | 17 | 44.7 |
| Transportation | 4 | 10.5 |
| All three Conditions | 1 | 2.6 |

Table 28 presents reasons given as contributing to the difficult working conditions. The reasons include the use of excess body energy (42.1%), hard to balance the tractor in a working track (18.4%), non-conducive environment (15.8%), stimulates discomfort of the body (10.5%), and that accelerates extreme body tiredness when supporting the tractor to turn sharply at headland (13.2%). The use of excess body energy; hauling the load on rough farm roads and difficulty control along the track, during transportation tend to increase both, the body fatigue and the magnitude of HTV and were seen by operators as most challenging.

**Table 28: Reasons to why some working conditions considered difficult (N= 38)**

| Probable reasons | Number of operators | Percentage |
|---|---|---|
| Use of Excess Body Energy | 16 | 42.1 |
| Non-conducive environment | 6 | 15.8 |
| Hard to balance the tractor | 7 | 18.4 |
| Stimulates discomfort of the body | 4 | 10.5 |
| Accelerates extreme tiredness | 5 | 13.2 |

In Table 28, use of excess body energy, non-conduciveness of work environment, difficulty handling and balancing of the hand tractor, stimulation of extreme tiredness and lack of working comfort were considered as factors that contribute to difficulty working conditions. During normal operations, single-axle tractor operators are directly subjected or exposed to extreme dusty or muddy conditions, varying solar radiation, unfavourable nature of the job that require muscular energy to support or lift at rear when turning at headland or when the tractor is submerged in muddy field. All these efforts combined with the exposure to extreme hand transmitted vibration add up to the body stress causing physiological and psychological fatigue to the operators.

Some of the main problems mentioned as associating to the difficulties of the field operations of single-axle tractors are indicated in Table 29. The problems were lack of safety gears (34.2%), exposure to extreme solar radiation (temperature) (13.2%), non-conducive environment of exhaust gases, dusty, vibration on supporting the tractor, noise and lifting of tractor that stimulates discomfort (18.4%), lack of proper knowledge on safe handling of the tractor (15.8%), use of muscular energy to control the tractor (13.2%) and poor farm preparation (5.3%).

**Table 29: Main problems in power tiller operations (N = 38)**

| Problems in power tiller operation | Number of operators | Percentage |
|---|---|---|
| Lack of safety gears | 13 | 34.2 |
| Exposure to extreme solar radiation | 5 | 13.2 |
| Stimulates discomfort | 7 | 18.4 |
| Lack of proper knowledge | 6 | 15.8 |
| Muscular Energy to control the tractor | 5 | 13.2 |
| Poor farm preparation | 2 | 5.3 |

Training to operators needs to be prerequisite before involved in actual field operations. The training will impart the necessary understanding to operators that will be enough to ensure a safe and friendly working environment through usage of safety gears necessary to reduce physical stresses associated with working environment that add up to body fatigue and work stress.

Table 30 presents some of the solutions proposed by operators that may reduce the magnitudes of vibration emitted to single-axle tractor operators. The operators need for the safety gears (57.9%), proper knowledge to operators (23.7%), Adding of weight to tillage attachment (2.6%), modification by inserting the vibration isolators between machine frame and engine mounting or the handle (7.9%) and about 7.9% of operators were unable to suggest any alternative solution.

**Table 30: Proposed solutions in power tiller operation problems (N = 38)**

| Probable solutions in power tiller operation | Number of operators | Percentage |
|---|---|---|
| Provide safety gears | 22 | 57.9 |
| Provide proper knowledge to operators | 9 | 23.7 |
| Add weight to tillage attachment | 1 | 2.6 |
| Modification required | 3 | 7.9 |
| No alternative solution | 3 | 7.9 |

Operators concurred with the notion that occupational health hazards were caused by regular use of hand-held vibratory tools in most agricultural environments but showed little knowledge on the precautions that might be helpful for improving their work environment. Operators (92.1%) agreed that regular use of hand-held vibratory tools in most cases are hazardous to health even though operating single-axle tractor serves as self employment to most of them (Table 31).

**Table 31: Regular use of vibratory tools are hazardous to health (N = 38)**

**Table 31: Regular use of vibratory tools are hazardous to health (N = 38)**

| Do you agree? | Number of operators | Percentage |
|---|---|---|
| Agree | 35 | 92.1 |
| Not agree | 3 | 7.9 |

Proper knowledge of work environment and ways of reducing exposure to vibration other than using safety gear is necessary to operators. Among interviewed operators, 68.4% were unaware of alternative ways of reducing exposure to vibration, 13.2% were using job rotation (sharing), 10.5% were operating the tractor and taking a rest in between bouts and 7.9% depended on a correct use and periodic maintenance of single-axle tractors (Table 32).

**Table 32: Minimizing the vibration effect without the use of anti-vibration devices**

| Minimizing vibration effects | Number of operators | Percentage |
|---|---|---|
| Operate and Rest | 4 | 10.5 |
| Job Rotation (Sharing) | 5 | 13.2 |
| Correct Use and Maintenance | 3 | 7.9 |
| No Alternative | 26 | 68.4 |

Understanding work environment and knowledge of ways of reducing exposure to vibration other than using safety gears is of great importance to operators. In the study, operators showed little knowledge of alternative ways of reducing vibration exposure; these ways include job sharing or job rotation, operate and rest between bouts and the correct use or maintenance of single-axle tractors. Practically, the periods of intense physical activity alternate with rest breaks or lighter work periods, however; Tiwari and

Gite (2006) found that very short breaks or operate and rest mode of vibration exposure reduction as being not desirable in the actual agricultural field operation (single-axle tractor operations) as it may cause more physiological fatigue which may subsequently lead to occupational accidents and or injuries.

### 4.3.3 Hand-arm vibration syndrome (HAVS) symptoms

The study found that operators of single-axle tractor experience occasional numbness in fingers, tingling in fingers, attacks of well-demarcated finger blanching, pain when exposed to cold, reduced grip strength and reduced finger flexibility which are typical signs and symptoms of HAVS. Major health problems associated with the use of vibrating hand-held tools are signs and symptoms of both, peripheral vascular and neural disorders of the fingers and hands as reported by NIOSH (1989). As discussed earlier, the magnitude of vibration increases as the speed of operation increases. Therefore, the increase of magnitude of vibration transmitted through hands is considered as stimuli and contributor to body and muscular fatigue that may cause detrimental effects to single-axle tractors operators. Also, similar observation were reported by Dong *et al*. (2001); Friden (2001); ISO (2001a).

These necessitates the importance of undertaking further experiments to establish actual magnitudes that may cause vibration damage to the operator’s hand and develop the relationship between the effects of HAVS and exposure to high magnitudes of HTV. However, Gerhardsson *et al*, (2005); Griffin, (1997) have both reported that the mechanisms by which hand transmitted vibration lead to tissue damage or the vascular, sensorineural and musculoskeletal outcomes of HAVS are not well understood.

#### 4.3.3.1 Vascular symptoms

The results do show that severe pains in hands; arms and shoulder are common among single-axle tractor operators. The risks for different operator vary for each component of HAVS depending on various individual and environmental factors. The results show that numbness, tingling of the fingers, colour changes in the fingertips, cold intolerance and finger blanching were experienced by operators during rest periods. Table 33 shows the operator's response to severity of pain in the hand, arm and shoulder after the completion of work per day in which; 2.6% reported mild pain, 50.0% reported moderate pain and 47.4% reported severe pain.

**Table 33: Severity of pain operator's arm, shoulder or hands (N = 38)**

| Severity of pain | Number of operators | Percentage |
|---|---|---|
| Mild Pain | 1 | 2.6 |
| Moderate pain | 19 | 50.0 |
| Severe pain | 18 | 47.4 |

Various studies report that occupational exposures to physical agents (vibration, cold and smoking) are the contributing factors that may cause vascular problems and can aggravate and cause vascular disease (Nelson, 2004; Griffin *et al*. 2003).

Operators reported the difficulties of performing other specific activities after working in the field due to pain in the hand, arm and shoulders as indicated in Table 34. Whereby, 2.6% of the total operators felt no pain, 10.5% felt mild pain and 78.9% felt moderate pain and 7.9% reported severe pain.

**Table 34: Arm, shoulder or hand pain when performing other activities (N = 38)**

| Pain when performing other activities | Number of operators | Percentage |
|---|---|---|
| No pain | 1 | 2.6 |
| Mild pain | 4 | 10.5 |
| Moderate pain | 30 | 78.9 |
| Severe pain | 3 | 7.9 |

The amount at which operators suffer from tingling in the hand, arm and shoulder are presented in Table 35, they report different degrees of severity; 34.2% of the operators indicated mild, 44.7% moderate and 21.1% severe tingling.

**Table 35: Tingling in operator's arm, shoulder or hands (N = 38)**

| Tingling in Arms, etc. | Number of operators | Percentage |
|---|---|---|
| Mild | 13 | 34.2 |
| Moderate | 17 | 44.7 |
| Severe | 8 | 21.1 |

Table 36 shows operator's response on numbness in fingers. About 68.4% of the total operators felt occasional numbness and 31.6% were not experiencing numbness.

**Table 36: Numbness in fingers (N = 38)**

| Do your fingers go numb? | Number of operators | Percentage |
|---|---|---|
| Yes | 26 | 68.4 |
| No | 12 | 31.6 |

Table 37 presents the observation by operators whereby; 81.6% experience numbness or tingling of the fingers at other times and 18.4% show no effect at other times.

**Table 37: Numbness or tingling of fingers at any other time (N = 38)**

| Do you have numbness or tingling of fingers at other times? | Number of operators | Percentage |
|---|---|---|
| Yes | 31 | 81.6 |
| No | 7 | 18.4 |

Numbness and tingling disturbance on other times were also reported by operators in Table 38. Specifying the occurrence of these effects, 48.4% indicated during rest in between bouts; 29% indicated after the completion of work; and 22.6% indicated the morning that follows. According to Griffin *et al*. (2003), there is a close correlation in the occurrence of numbness, finger tactile perception deterioration and lack of manipulative dexterity with the presence of hand transmitted vibration.

**Table 38: In Which time it occurs? (specify time) (N = 31)**

| If yes, in which time it occurs? | Number of operators | Percentage |
|---|---|---|
| Between work bouts | 15 | 48.4 |
| After completing work | 9 | 29 |
| Next morning | 7 | 22.6 |

Responding to their experience on colour changes in fingers (Table 39); 76.3% of operators reported to have been occasionally affected by colour changes in fingers, while 23.7% reported no colour changes in the fingers.

**Table 39: Colour change in fingers (N = 38)**

| Have you experienced colour change? | Number of operators | Percentage |
|---|---|---|

**Table 39:** **Colour change in fingers (N = 38)**

| | | |
|---|---|---|
| Yes | 29 | 76.3 |
| No | 9 | 23.7 |

In Table 40, operators were of the opinion that colour changes in the hand and fingers were significant when working in the cold, damp or wet environment (69%), 27.6% of the total operators reported colour changes while performing soil tillage operations and the remaining 3.4% of the total operators noted no colour change for all operations.

**Table 40:** **Specify when does it occur (N = 29)**

| If Yes, when does it occur? | Number of operators | Percentage |
|---|---|---|
| Response to cold or wetness | 20 | 69 |
| Working in soil tillage | 8 | 27.6 |
| Do not remember | 1 | 3.4 |

#### 4.3.3.2 Neurological symptoms

Some operators indicated difficulties to grasp hands to handle small objects immediately after working in the field with single-axle tractors. About 76.3% of the operators interviewed, experienced difficulties in picking up, handling or manipulating small objects such as screws, buttons and small needles; while 23.7% indicated no difficulties in handling small objects (Table 41).

**Table 41: Difficulty in picking up or manipulating small objects (N = 38)**

| Do you feel difficulty in picking objects? | Number of operators | Percentage |
|---|---|---|

**Table 41: Difficulty in picking up or manipulating small objects (N = 38)**

| | | |
|---|---|---|
| Yes | 29 | 76.3 |
| No | 9 | 23.7 |

Nerve effects due to exposure to vibrating objects were reported during the study. The symptoms observed by single-axle tractor operators during the study include numbness and tingling, loss of sensation in the fingers, sleeping disturbances, muscle fatigue and weakness, impaired skin sensitivity and decreased ability to sense vibration; and occasionally, operators experienced loss of hand dexterity.

Various studies report that the neurological component is characterized by nerve effects that include numbness in the fingers, impairment of tactile function and musculoskeletal abnormalities in the hands and arms with predominated sensory impairment and sensorineural disturbances (House *et al*. 2009; Bovenzi, 2000). Recovery of nerve function after discontinuation of vibration exposure is less likely than the reversal of vascular effects.

Tables 42 shows that 86.8% of the interviewed operators experience reduced gripping capability of their dominant hand, and 13.2% reported not to have been affected in the hand gripping. Weaknesses in the hand grip were specifically reported in left hand by 30.3%, with the right hand by 24.2%, and with both hands by 45.5% of the total interviewed operators as indicated in Table 43. The decreased grip strength relates to a combination of direct muscle and nerve injuries due to exposure to vibration. Nelson, 2004; Necking *et al*., 2003; NIOSH, 1997 have indicated that the reduced muscle strength in the abduction of the index finger indicates the effects of hand-arm vibration syndrome caused by hand transmitted vibration.

**Table 42: Suffer from weakness in hand grip (N = 38)**

| Weakness in hand gripping | Number of operators | Percentage |
|---|---|---|
| Yes | 33 | 86.8 |
| No | 5 | 13.2 |

**Table 43: Specify hand(s) (N = 33)**

| If yes, which hand(s)? | Number of operators | Percentage |
|---|---|---|
| Left | 10 | 30.3 |
| Right | 8 | 24.2 |
| Both | 15 | 45.5 |

Ill-health conditions also include sleeping disturbances, interference to emotional problems, body weaknesses or incapability and numbness or tingling at other times of the day. Responding to sleeping disturbances, 5.3% reported not to have been disturbed at all, 7.9% reported slight disturbances, 55.3% were moderately disturbed, 28.9% experience high disturbances and the remaining 2.6% reported very high disturbances (Table 44).

**Table 44: Difficulty sleeping due to pain in arms, shoulders or hands (N = 38)**

| How much difficulty sleeping? | Number of operators | Percentage |
|---|---|---|
| Not at all | 2 | 5.3 |
| Slight | 3 | 7.9 |
| Moderate | 21 | 55.3 |

**Table 44: Difficulty sleeping due to pain in arms, shoulders or hands (N = 38)**

| | | |
|---|---|---|
| High | 11 | 28.9 |
| Very high | 1 | 2.6 |

Table 45 shows that 84.2% of the total operators experience tingling in the fingers and 15.8% reported no effect of finger tingling.

**Table 45: Tingling in fingers (N = 38)**

| Have you experienced tingling in fingers? | Number of operators | Percentage |
|---|---|---|
| Yes | 32 | 84.2 |
| No | 6 | 15.8 |

Table 46 shows that 76.3% experience muscles or joint troubles in the neck and 23.7% were not experiencing muscular pain in the neck.

**Table 46: Muscle or joint troubles in the neck (N = 38)**

| Do you suffer from muscle trouble in the neck? | Number of operators | Percentage |
|---|---|---|
| Yes | 29 | 76.3 |
| No | 9 | 23.7 |

#### 4.3.3.3 Musculoskeletal symptoms

Tables 47 and 48 show ill-health conditions felt by most operators in the neck and shoulder. About 36.8% of the operators experience slight pain, moderate pain (57.6%) and severe pain (5.3%) in the neck. Responding to the occurrence of shoulder pain or problems, 2.6% reported no pain, 26.3% experience slight pain, 60.5% experiences moderate pain and 10.5% reported severe pain.

**Table 47: Pain or problems with neck (N = 38)**

| Do you have neck problems? | Number of operators | Percentage |
|---|---|---|
| Slight | 14 | 36.8 |
| Moderate | 22 | 57.9 |
| High | 2 | 5.3 |

The study reports loss of strength in the hands and pain in the arms, wrist or shoulder of single-axle tractor operators. Vibration induced health conditions progress slowly. Pain noticed early should be addressed in order to stop progression to injury.

**Table 48: Pain or problems with shoulder (N = 38)**

| Do you have shoulder problems? | Number of operators | Percentage |
|---|---|---|
| Not at all | 1 | 2.6 |
| Slight | 10 | 26.3 |
| Moderate | 23 | 60.5 |
| High | 4 | 10.5 |

Ill-health conditions were reported also in the arms and hands or wrists as indicated in Tables 49 and 50. Operators that experience no pain at all in the arms were 2.6%, slight pain (13.2%), moderate pain (60.5%) and severe pain (23.7%). Responding to the occurrence of pain or problems in the hands or wrists, operators who had no pain were

5.3%, slight pain were 2.6%, moderate pain were 26.3%, severe pain were 57.9% and very severe pain were 7.9% of the total interviewed respondents.

**Table 49: Pain or problems with arms (N = 38)**

| Do you have arm problems? | Number of operators | Percentage |
|---|---|---|
| Not at all | 1 | 2.6 |
| Slight | 5 | 13.2 |
| Moderate | 23 | 60.5 |
| High | 9 | 23.7 |

**Table 50: Pain or problems with hand or wrists (N = 38)**

| Do you have hand or wrist problems? | Number of operators | Percentage |
|---|---|---|
| Not at all | 2 | 5.3 |
| Slight | 1 | 2.6 |
| Moderate | 10 | 26.3 |
| High | 22 | 57.9 |
| Very high | 3 | 7.9 |

Weak performances of the hand, arm and shoulder were observed by operators, whereby 15.8% reported fairly weak, 73.7% reported moderately weak and 10.5% felt severe weakness (Table 51).

**Table 51: Weakness in operator's arm, shoulder or hands (N = 38)**

| Weakness in arms, etc. | Number of operators | Percentage |
|---|---|---|
| Fairly weak | 6 | 15.8 |

**Table 51: Weakness in operator's arm, shoulder or hands (N = 38)**

| | | |
|---|---|---|
| Moderate | 28 | 73.7 |
| Highly weak | 4 | 10.5 |

Table 52 shows the extent at which sleeping disturbances occur and which include awaking at night as reported by operators. About 23.7% experience sleepless nights and 71.1% become awake at night though not regularly.

**Table 52: Sleepless nights due to pain, tingling or numbness in hand (N = 38)**

| Do You Wake at Night With Pain or Numbness? | Number of operators | Percentage |
|---|---|---|
| Yes | 9 | 23.7 |
| No | 2 | 5.3 |
| Not always | 27 | 71.1 |

Responding to the question on the extent at which physical health or emotional problems have been interfered with social activities (Table 53), operators had the following opinion; 15.8% said slightly, 78.9% said moderately and 5.3% said were highly interfered.

**Table 53: Physical or emotional problem interference to social activities (N = 38)**

| To What Extent Your Physical Health interfered? | Number of operators | Percentage |
|---|---|---|
| Slightly | 6 | 15.8 |
| Moderately | 30 | 78.9 |
| Quite High | 2 | 5.3 |

In Table 54, the perceptions of operators on general body weakness (feeling weak or less capable) were reported, whereby those who reported no weakness at all were 2.6%, slight body weakness were 15.8%, moderately weak were 78.9%, and highly weak were 5.3%.

**Table 54: Feeling less useful due to arm, shoulder or hand problems (N = 38)**

| I feel less confident because of my hand/arm problems | Number of operators | Percentage |
|---|---|---|
| Not at all | 1 | 2.6 |
| Slight | 5 | 13.2 |
| Moderate | 30 | 78.9 |
| High | 2 | 5.3 |

Table 55 presents operator's comment on their general health in comparison to the previous year; those operators who reported being in much worse health were 2.6%, health was somewhat worse were 50%, those who reported being in the same health condition were 44.7% and somewhat better were 2.6% of the total interviewed operators.

**Table 55: Rate your health history (N = 38)**

| How would you rate your health in general now? | Number of operators | Percentage |
|---|---|---|
| Much worse | 1 | 2.6 |
| Somewhat worse | 19 | 50.0 |
| Same | 17 | 44.7 |
| Somewhat better | 1 | 2.6 |

Responding to their general health conditions after years of operating single-axle tractors, 2.6% declared to be in poor health, 39.5% in fair health, 50% in good health and 7.9% in very good health conditions as illustrated in Table 56.

During field survey, 38 single-axle tractor operators cited physical labour such as lack of proper training and skills on the required degree of interface required for human-machine (coupling); the actual working time in the field during seedbed preparation exceeds 8-hours that are used to evaluate exposure time; lack of safety gears; exposure to extreme solar radiation; use of extra muscular energy to control the tractor and manoeuvre at headlands and poor farm preparation which contributes to fatigue and discomfort during operation.

The study demonstrates the susceptibility of operators to the effects of HAVS. The operators were in opinion that, they experiences tingling and pain in arms, shoulders and hand; numbness in fingers; feel difficulty in picking, handling or manipulating small objects such as screws; suffer from weakness in hand grip; have difficulty sleeping because of the pain in arms, shoulder or hands and some operators agree that their physical health or emotional problem interfered with normal social activities. As seen during literature review; these symptoms shows the presence of vibration-induced disorders in its early stages to operators that if not diagnosed and attended in time, may develop to disorders that may result to impairment of life quality and disability of the affected operator.

**Table 56: General health of operators (N = 38)**

| What is your general comment on the healthy trend? | Number of operators | Percentage |
|---|---|---|
| Poor | 1 | 2.6 |
| Fair | 15 | 39.5 |
| Good | 19 | 50.0 |
| Very Good | 3 | 7.9 |

### 4.4 Carpal tunnel syndrome (CTS) symptoms

The current study observes that many signs and symptoms of CTS (Fig. 11) have equivalency to the signs and symptoms of HAVS. That is; the study further observes that physical activities involved in the operation of single-axle tractor may also contribute to the development of CTS. These necessitate the importance of conducting further studies on HTV in order to classify specific disorders that are mainly due to exposure to vibration from handles of single-axle tractor transmitted to operators and those for CTS.

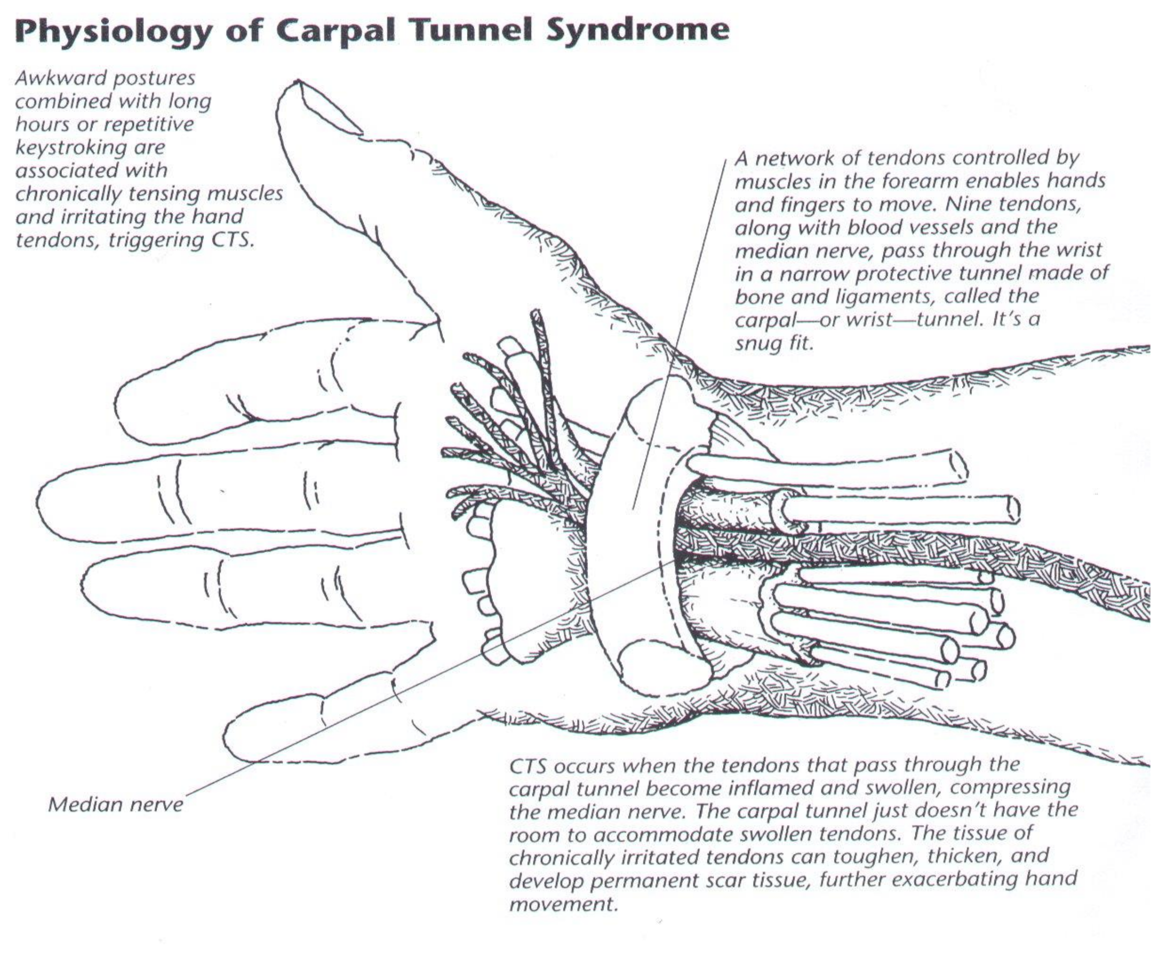



**Figure 21: Physiology of Carpal Tunnel Syndrome** Source: **A.D.A.M Medical Encyclopaedia; [www.ncbi.nlm.nih.gov/pubmedhealth/PM0001469](www.ncbi.nlm.nih.gov/pubmedhealth/PM0001469))**

### 4.5 Comparison to standards related to hand transmitted vibration

The effects imposed to human hand-arm system from exposure to mechanical vibration are known to most occupational safety and health authorities. The machinery safety directive of the European Community (89/392/EEC) describes that, vibration data measurements only does not ensure safe and healthier working of equipment but efforts must be kept to improve design of equipment so as to include human factors that would provide comfortable and safe work environment. The standards and guidelines relating to HTV considered in this study are: ISO 5349-1 (2001a), BS 6842 (1987), the directive 2002/44/EC, ANSI S2.70 (2006) and ACGIH (2003).

#### 4.5.1 International Standard Organisation (ISO 5349-1; 2001)

The total vibration values found in the actual agricultural practice (Tables 9: (1-4)) were higher than the tentatively recommended by the ISO 5349 (2001b) standard (Table 3.1). Higher exposures to vibration presumably carry increased health risk towards vibration-induced disorders (Nelson, 2004). Therefore operators need to spend much less time in operation than they actually do during intensive farm preparation period, because the four studied single-axle tractors transmit very high vibration magnitude. Taking the field results as the basis of this report Tables 10 (1-4) show that operators of single-axle tractor are susceptible to developing symptoms of VWF within very short periods. Operators need proper understanding and taking necessary measure to avoid excessive exposure or to reduce exposure duration to mechanical vibrations transmitted through the hands, arms and shoulders.

### 4.5.2 Directive 2002/44/EC

The directive suggest that vibration measurement should not be the only means of assessing vibration hazard, where machine use is known to cause vibration-induced disorders; this presumably means it presents a health risk irrespective of the vibration exposure measured. The ELV only sensitizes the importance of maintaining lower vibration magnitude levels in order to reduce the possibility of operators falling victims of vibration-induced health risks. Tables 9(1-4) presents quantitative results of the field observations for four studied single-axle tractors. The magnitude of vibration in three operational modes fall out of the given boundary (ELV), which indicates that the operators are exposed to detrimental effects caused by HTV.

### 4.5.3 British Standard (BS 6842; 1987)

Tables 10 (1-4) present the prediction of lifetime exposure to HTV to operators from the studied single-axle tractors in three operational modes. It, therefore, reveals the susceptibility of operators of single-axle tractor to symptoms of vibration-induced white finger within very short times. BS 6842 (1987) recommend that operators working with hand-held tools which transmits high vibration magnitude spend less time in operation and vice versa.

### 4.5.4 American National Standard Institute (ANSI S2.70; 2006)

Practical situation observed during field experiments reveals that, with different make of single-axle tractors, different operator skills, different working speed and different field soil conditions, the daily vibration exposure values A(8) are higher than the recommended Daily Exposure Action Values (DEAV) and Daily Exposure Limit Values (DELV). ANSI S2.70 (2006) suggests DELV of 5 $m/s^2$ be the maximum value above which operators need not be exposed. Therefore, the study results indicate that single-axle tractor operators are susceptible to very high effects of vibration-induced disorders.

### 4.5.5 American Conference of Governmental Industrial Hygienists

The experimental observations of the study presented in Tables 8(1-4) and Tables 9(1-4) for the studied single-axle tractors lay beyond the boundary bands of either using TLV in dominant axis or the vibration total values. Therefore the results show a relative susceptibility of operators to the detrimental effects of HTV. The ACGIH demonstrates that higher exposures to vibration presumably carries increased health risk towards vibration-induced disorders and that operators need to spend less time in operation.

### 4.5.6 General study results-standard comparison

The study results generally show that the vibration magnitude exceeds both EAV and ELV defined by the European Union which are 2.5 $m/s^2$ and 5 $m/s^2$ respectively. The study highlights and reveals that operators depend on operations of single-axle tractors for their livelihood and family support. Non conducive working environment and exposure to high magnitudes of the HTV may subject operators to physical strength impairment resulting to detrimental healthy effects or injuries.

Therefore, eliminating or reducing vibration on the handles of single-axle tractor to the lowest possible level is the best alternative. Elimination or reduction of vibration can be done through good engineering design of the equipment to include vibration dampers, addressing environmental conditions that accelerate fatigue, and other factors such as human anatomy, anthropometric, physiological and human-machine system characteristics, i.e. working postures, workplace layout, safety and health as they relate to physical activity.

# CHAPTER FIVE

## 5. CONCLUSIONS AND RECOMMENDATIONS

It is apparent that single-axle tractor plays a key role in the mechanization of agriculture to small and medium farmers in Tanzania. For such dependency, the ergonomic characteristics such as exposure to HTV assume a great importance. This chapter presents the conclusions and recommendations drawn from the results of the study.

### 5.1 Conclusions

Based on the field experimental results and questionnaire analysis the following conclusions can be drawn:

i. The magnitudes of vibration during tillage operation varies between 6.481 m/s$^2$ at 1.54 km/hr to 7.834 m/s$^2$ at 4.51 km/hr for AMEC; 7.908 m/s$^2$ at 1.95 km/hr to 8.442 m/s$^2$ at 5.70 km/hr for GREAVES; 5.350 m/s$^2$ at 1.11 km/hr to 7.856 m/s$^2$ at 2.92 km/hr for KUBOTA; and 6.012 m/s$^2$ at 1.04 km/hr to 10.263 m/s$^2$ at 7.14 km/hr for YANMAR.

ii. The magnitudes of vibration during rota-puddling operation varies between 5.817 m/s$^2$ at 1.54 km/hr to 6.330 m/s$^2$ at 4.51 km/hr for AMEC; 6.033 m/s$^2$ at 1.95 km/hr to 7.739 m/s$^2$ at 5.70 km/hr for GREAVES; 4.250 m/s$^2$ at 1.11 km/hr to 4.445 m/s$^2$ at 2.92 km/hr for KUBOTA and 5.271 m/s$^2$ at 1.04 km/hr to 5.606 m/s$^2$ at 2.14 km/hr for YANMAR.

iii. The study results further show that; the magnitudes of vibration during transportation operation varies between 10.067 m/s$^2$ at 1.95 km/hr to 10.234 m/s$^2$

at 5.70 km/hr for GREAVES; 6.013 $m/s^2$ at 1.11 km/hr to 6.871 $m/s^2$ at 2.92 km/hr for KUBOTA and 5.622 $m/s^2$ at 1.04 km/hr to 6.903 $m/s^2$ at 2.14 km/hr for YANMAR.

iv. It is evident that handles of single-axle tractors transmit higher magnitudes of mechanical vibrations to operator's hands that may cause a variety of vibration-induced disorders collectively known as hand-arm vibration syndrome. Excessive hand-arm vibration felt at the hand grip is the source of increased fatigue and observed as the important shortcoming in the field operation of single-axle tractors.

v. Acceleration levels increased with the increase in forward speed under all operating conditions. The magnitudes of vibration total values varied widely due to variation in the type of single-axle tractors, mode of operation, forward speed, terrain conditions and operating technique. The magnitudes of vibration were the highest during transportation followed by tilling and rota-puddling operations.

vi. The vibration acceleration total values ($a_{hv}$) in three operational modes, exceed both suggested Exposure Action Value (EAV) equivalent to 2.5 $m/s^2$, ($A(8) > 2.5$ $m/s^2$) and Exposure Limit Value (ELV) equivalent to 5 $m/s^2$, ($A(8) > 5$ $m/s^2$).

vii. The prevalence of 10% exposed operators to show signs and symptoms of VWF when operating single-axle tractors at full load are estimated to be 4 years for AMEC, 5 years for YANMAR, 3 to 4 years for GREAVES and 5 to 7 years for KUBOTA operators.

viii. Hand transmitted vibration along $x_h$-axis was found most significant for all operating conditions and appeared to be more severe than those in horizontal ($y_h$-axis) and lateral ($z_h$-axis) directions under the same test conditions.

ix. Eliminating or reducing vibration on the handles of single-axle tractor to the lowest possible level is seen as good practice. These can be done through good engineering design of the equipment to include vibration dampers, addressing environmental conditions that accelerate fatigue, and other factors such as human anatomy, anthropometric, physiological and human-machine system characteristics.

x. The study shows the presence of symptoms of vibration-induced disorders in its preliminary stages to operators, which if not diagnosed and attended in time, may develop to disorders that will result to impairment of life quality and disability of the affected operator.

## 5.2 Recommendations

From the study findings, the following recommendations are made:

i. During labour-intensive agricultural practice, female and young operators (less than 18 years) must be discouraged from operating single-axle tractors because response to stronger physical intensity of HTV is significantly sensitive to age and gender differences. Young ages are more vulnerable to the musculoskeletal injury caused by soft bone density.

ii. Single-axle tractor manufacturers should consider redesigning of handles or engine mounting to the chassis by including vibration dampers to ensure least hand-arm vibration are transmitted from handles to operator's hands, arms and shoulders.

iii. Decrease the exposure duration and vibration magnitude to the existing single-axle tractors by either working at low forward speed, work scheduling, job rotation (allow work-rest periods) or use of anti-vibration gloves.

iv. Proper training on the basics of single-axle tractors handling and operations should be offered to operators before allowed to operate single-axle tractors.

v. Single-axle tractor operator's need to attend medical check up after each farming season for diagnosing any microscopic damage to the hand-arm system as they start as a pain and progressively develop to a complex vibration induced disorder as the exposure to vibration continues.

vi. Further research studies and field experiments are required in different agro-ecological zones in order to determine the magnitudes of HTV and establish the justifiable factors that contribute to the occurrence of HAVS among single-axle tractor operators in Tanzania.

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# APPENDICES

## A: Questionnaire for single-axle tractor operators.

A STUDY ON HAND TRANSMITTED MECHANICAL VIBRATIONS AND SHOCKS TO OPERATORS OF SINGLE-AXLE TRACTORS DURING FIELD OPERATIONS.

### 1.0 Personal Identification

Respondent's Name ……………………………………………………………

Date of Interview ……………………………………………………………

Division ……………………………………………………………………

Name of the Village …………………………………………………………

Ward …………………………………………………………………………

District ………………………………………………………………………

1.1 Respondent Number …………………………………………………..

1.2 Age …………………………………………………..

1.3 Gender ……………………………………………….

1.4 Height ………………………………………………..

1.5 Weight ……………………………………………….

1.6 Dominant hand …………………………………………

1.7 Marital Status …………………………………………..

1.8 Level of Education ……………………………………….....................

1.9 Are you self-employed as power tiller operator? ………………………

1.10 Have you ever smoked regularly (i.e. at least once a day for a month or longer)? ……………………………………………………

1.11 If yes, how old were you when you first smoked regularly? …………...

1.12 Do you still smoke regularly? …………………………………………..

1.13 If no, how old were you when you last smoked regularly? …………….

1.14 Does smoking habit helpful to your carrier? ……………………………

1.15 In your spare time (outside work), have you ever used a tool or hand held machine that made your hands vibrate for more than one hour per week? ........................................................................................

## 2.0 Machine Knowledge and Use

2.1 Do you have prior knowledge on how to operate power tillers? …………………

2.2 Where did you attend training to become power tiller operator? …………………

2.3 How you felt hard on your first day as power tiller operator? …………………......

2.4 Have you ever sustained an injury to your neck, shoulder, arm or hand? ……….

2.5 How many hour(s) do you spend in operation per day? ………………………….

2.6 How long have you been operating power tillers? ………………………………

2.7 How do you know that you have applied the required pressure in gripping the handle? ………………………………………………………………………..

2.8 What working condition you consider more difficult to operate the power tiller? ………………………………………………………………………………

2.9 What do you consider to be the main problems associated with such working condition? ……………..........................................................................................

2.10 What do you consider to be the main problems in power tiller operation? ………………………………………………………………………………

2.11 What do you consider to be the most probable solutions to the problems mentioned above? ……………………………………………………………….

2.12 Do you agree that regular use of vibratory tools is hazardous to your health? ……………………………..........................................................................

2.13 Are you aware of any devices that can protect you from the vibration hazard? ……………………………………………………………………………...

2.14 If an anti-vibration device is not provided, what do you do to minimize the vibration effect? …………………………………………………………...

2.15 What is your future plan in this carrier? ……………………………………..

**3.0 Hand and Musculoskeletal Symptoms**

Please rate the severity of the following symptoms after completing your work per day:

3.1 Arm, Shoulder or hand pain [0 = No pain, 1 = Fairly Painless, 2 = Moderate Pain, 3 = High Pain, 4 = Extreme Pain]

3.2 Arm, Shoulder or hand when you perform any specific activity [0 = No pain, 1 = Fairly Painless, 2 = Moderate Pain, 3 = High Pain, 4 = Extreme Pain]

3.3 Tingling (Pins and needles) in your Arm, Shoulder or hand [0 = No Pain, 1 = Fair, 2 = Moderately, 3 = High, 4 = Extremely]

3.4 Weaknesses in your arm, shoulder or hand [0 = No Weakness, 1 = Fairly Weak, 2 = Moderately weak, 3 = High weakness, 4 = Extremely weak]

3.5 Do your fingers go numb? ……………… [1 = Yes, 2 = No]

3.6 Do you have pain or problems with your neck? [0 = Not at all, 1 = Slightly, 2 = moderately, 3 = Quite high, 4 = Very high]

3.7 Do you have pain or problems with your shoulder? [0 = Not at all, 1 = Slightly, 2 = moderately, 3 = Quite high, 4 = Very high]

3.8 Do you have pain or problems with your arm? [0 = Not at all, 1 = Slightly, 2 = moderately, 3 = Quite high, 4 = Very high]

3.9 Do you have pain or problems with your hand/wrist? [0 = Not at all, 1 = Slightly, 2 = moderately, 3 = Quite high, 4 = Very high]

3.10 Do you feel difficulty in picking up, handling or manipulating small objects (e.g. screws, buttons, small needles, etc)? ……………………………………….

3.11 Do you suffer from weakness in your hand grip? …………………………......

3.12 If yes, which hand(s)? ……………………………………………………...

3.13 Have you ever experienced a tingling (pin and needles) sensation in your fingers? ……………………………………………………………………….

3.14 Do you suffer from muscle or joint troubles in the neck? …………………….

3.15 Have you ever experienced any colour change in your fingers at any time? ………………………………………………………………………………..

3.16 If Yes, When does it occur? ……………………………………………….

3.17 Are you experiencing any other problems with the muscles or joints of the hands or arms? ……………………………………………………………..

3.18 How much difficulty have you had sleeping because of the pain in your arms, shoulders or hands? ………………… [0 = Not at all, 1 = Slightly, 2 = moderately, 3 = Quite high, 4 = Very high]

3.19 To what extent your physical health or emotional problem interfered with normal social activities with family, friends, neighbours or groups? …… [0 = Not at all, 1 = Slightly, 2 = moderately, 3 = Quite high, 4 = Very high]

3.20 I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. ……………… [0 = Not at all, 1 = Slightly, 2 = moderately, 3 = Quite high, 4 = Very high]

3.21 Have you ever had a neck, arm, or hand injury or operation? …………………...

3.22 Do you wake at night with pain, tingling, or numbness in your hand or wrist? …………………………………………………………………………….....

3.23 Do you have numbness or tingling of the fingers at any other time? …………....

3.24 If the answer above is yes, in which time it occurs? (Specify time) …………….

3.25 Compared to one year ago, how would you rate your health in general now? ……………………………………………………………………………

3.26 Generally, would you say your health is ……………………………………....

**B: Vibration Total Values ($a_{hv}$ m/s$^2$) for Three Working Conditions**

**1: AMEC S. 1100 $A_2$**

| Operation Mode | Speed (km/hr) | Acceleration Direction | Operators | | | | | Mean Value ± Std Deviation | Vibration Total Values ($a_{hv}$ m/s$^2$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | |
| | | $x_h$ | 5.297 | 5.131 | 5.091 | 5.140 | 5.209 | 5.173 ± 0.07 | |
| | 1.54 | $y_h$ | 2.217 | 2.120 | 2.021 | 2.099 | 2.286 | 2.149 ± 0.09 | 6.481 |
| | | $z_h$ | 3.130 | 3.257 | 3.384 | 3.247 | 3.277 | 3.259 ± 0.08 | |
| | | $x_h$ | 6.014 | 5.689 | 5.258 | 5.935 | 5.474 | 5.674 ± 0.28 | |
| **Tillage** | 2.75 | $y_h$ | 2.629 | 2.502 | 2.698 | 2.433 | 2.423 | 2.537 ± 0.11 | 7.290 |
| | | $z_h$ | 3.914 | 3.747 | 3.581 | 3.806 | 4.002 | 3.810 ± 0.14 | |
| | | $x_h$ | 5.945 | 6.053 | 6.220 | 6.259 | 5.945 | 6.084 ± 0.13 | |
| | 4.51 | $y_h$ | 2.551 | 2.560 | 2.443 | 2.560 | 2.600 | 2.543 ± 0.05 | 7.834 |
| | | $z_h$ | 4.434 | 4.248 | 4.071 | 4.346 | 4.052 | 4.230 ± 0.15 | |
| | | $x_h$ | 3.855 | 6.465 | 5.131 | 5.160 | 4.091 | 4.940 ± 0.93 | |
| | 1.54 | $y_h$ | 2.168 | 2.325 | 2.325 | 2.266 | 2.443 | 2.305 ± 0.09 | 5.817 |
| | | $z_h$ | 1.658 | 2.188 | 1.972 | 2.207 | 2.129 | 2.031 ± 0.20 | |
| | | $x_h$ | 4.807 | 4.885 | 4.611 | 5.101 | 5.229 | 4.927 ± 0.22 | |
| **Rota-Puddling** | 2.75 | $y_h$ | 3.139 | 2.403 | 2.923 | 2.953 | 3.022 | 2.888 ± 0.25 | 6.232 |
| | | $z_h$ | 3.051 | 2.021 | 2.521 | 2.246 | 2.629 | 2.494 ± 0.35 | |
| | | $x_h$ | 4.444 | 4.336 | 4.768 | 4.454 | 4.895 | 4.579 ± 0.21 | |
| | 4.51 | $y_h$ | 3.404 | 3.286 | 3.384 | 3.443 | 3.139 | 3.331 ± 0.11 | 6.330 |
| | | $z_h$ | 2.815 | 2.904 | 2.914 | 2.835 | 2.678 | 2.829 ± 0.08 | |

**2: GREAVES GS – 15DIL.**

| Operation Mode | Speed (km/hr) | Acceleration Direction | Operators | | | | | Mean Value ± Std Deviation | Vibration Total Values ($a_{hv}$ $m/s^2$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | |
| | | $x_h$ | 6.435 | 6.583 | 6.661 | 6.563 | 6.965 | 6.641 ± 0.18 | |
| | 1.95 | $y_h$ | 2.580 | 2.649 | 2.835 | 2.678 | 2.865 | 2.721 ± 0.11 | 7.908 |
| | | $z_h$ | 3.198 | 3.178 | 3.365 | 3.365 | 3.502 | 3.322 ± 0.12 | |
| | | $x_h$ | 6.916 | 6.759 | 6.877 | 6.887 | 6.975 | 6.883 ± 0.07 | |
| **Tillage** | 3.40 | $y_h$ | 2.845 | 2.678 | 2.874 | 2.855 | 2.943 | 2.839 ± 0.09 | 8.325 |
| | | $z_h$ | 3.218 | 4.071 | 3.394 | 3.640 | 4.297 | 3.724 ± 0.41 | |
| | | $x_h$ | 6.985 | 6.896 | 7.044 | 6.965 | 7.024 | 6.983 ± 0.05 | |
| | 5.70 | $y_h$ | 3.218 | 3.188 | 3.198 | 3.316 | 3.286 | 3.241 ± 0.05 | 8.442 |
| | | $z_h$ | 3.316 | 3.532 | 3.227 | 3.816 | 3.434 | 3.465 ± 0.20 | |
| | | $x_h$ | 5.396 | 4.150 | 5.258 | 4.199 | 4.778 | 4.756 ± 0.52 | |
| | 1.95 | $y_h$ | 2.099 | 1.942 | 3.120 | 2.325 | 2.374 | 2.372 ± 0.40 | 6.033 |
| | | $z_h$ | 2.933 | 2.217 | 3.404 | 3.012 | 2.708 | 2.855 ± 0.39 | |
| | | $x_h$ | 5.327 | 5.651 | 4.699 | 5.572 | 5.798 | 5.409 ± 0.39 | |
| **Rota-Puddling** | 3.40 | $y_h$ | 2.129 | 2.629 | 3.277 | 2.639 | 2.433 | 2.621 ± 0.38 | 6.812 |
| | | $z_h$ | 2.717 | 3.012 | 3.483 | 3.640 | 3.178 | 3.206 ± 0.33 | |
| | | $x_h$ | 5.651 | 5.798 | 6.053 | 5.690 | 5.964 | 5.831 ± 0.16 | |
| | 5.70 | $y_h$ | 2.590 | 3.914 | 3.532 | 2.737 | 3.787 | 3.312 ± 0.55 | 7.739 |
| | | $z_h$ | 3.110 | 4.228 | 3.875 | 4.110 | 3.993 | 3.863 ± 0.39 | |
| | | $x_h$ | 7.993 | 8.142 | 8.397 | 7.720 | 7.760 | 8.002 ± 0.25 | |
| | 1.95 | $y_h$ | 4.375 | 4.670 | 5.189 | 3.963 | 4.375 | 4.514 ± 0.41 | 10.067 |
| | | $z_h$ | 4.277 | 4.159 | 4.581 | 3.551 | 4.012 | 4.116 ± 0.39 | |
| | | $x_h$ | 9.133 | 8.368 | 8.417 | 8.319 | 7.848 | 8.417 ± 0.41 | |
| **Transportation** | 3.40 | $y_h$ | 4.601 | 4.336 | 4.336 | 4.042 | 4.110 | 4.285 ± 0.20 | 10.168 |
| | | $z_h$ | 3.708 | 3.895 | 3.846 | 3.816 | 3.561 | 3.765 ± 0.12 | |
| | | $x_h$ | 9.261 | 8.427 | 8.809 | 8.751 | 8.407 | 8.731 ± 0.31 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5.70 | $y_h$ | 3.738 | 3.953 | 3.914 | 3.836 | 4.130 | 3.914 ± 0.13 | 10.234 |
| | | $z_h$ | 3.463 | 3.826 | 3.708 | 3.640 | 3.512 | 3.630 ± 0.13 | |

**3: KUBOTA K120-RK 125**

| Operation Mode | Speed (km/hr) | Acceleration Direction | Operators | | | | | Mean Value ± Std Deviation | Vibration Total Values ($a_{hv}$ m/s$^2$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | |
| | | $x_h$ | 3.170 | 3.914 | 4.640 | 3.944 | 4.689 | 4.071 ± 0.56 | |
| | 1.11 | $y_h$ | 2.100 | 2.266 | 2.335 | 2.413 | 2.099 | 2.243 ± 0.13 | 5.350 |
| | | $z_h$ | 2.364 | 2.590 | 3.208 | 2.453 | 2.629 | 2.649 ± 0.30 | |
| | | $x_h$ | 4.483 | 5.317 | 5.778 | 4.513 | 5.356 | 5.089 ± 0.51 | |
| **Tillage** | 1.70 | $y_h$ | 2.168 | 2.541 | 2.825 | 2.884 | 2.080 | 2.500 ± 0.33 | 6.348 |
| | | $z_h$ | 2.864 | 2.825 | 2.865 | 2.904 | 2.815 | 2.855 ± 0.03 | |
| | | $x_h$ | 5.240 | 5.866 | 6.592 | 6.720 | 5.366 | 5.957 ± 0.61 | |
| | 2.92 | $y_h$ | 3.375 | 3.443 | 3.178 | 3.630 | 3.247 | 3.375 ± 0.16 | 7.856 |
| | | $z_h$ | 4.415 | 3.581 | 3.326 | 4.444 | 3.492 | 3.852 ± 0.48 | |
| | | $x_h$ | 2.502 | 3.178 | 3.169 | 3.198 | 3.273 | 3.064 ± 0.28 | |
| | 1.11 | $y_h$ | 2.129 | 1.854 | 2.021 | 1.942 | 2.031 | 1.995 ± 0.09 | 4.250 |
| | | $z_h$ | 2.237 | 1.952 | 2.119 | 2.148 | 2.374 | 2.166 ± 0.14 | |
| | | $x_h$ | 3.483 | 3.178 | 3.571 | 3.326 | 3.728 | 3.457 ± 0.19 | |
| **Rota-Puddling** | 1.70 | $y_h$ | 1.501 | 1.913 | 1.864 | 1.805 | 1.619 | 1.740 ± 0.16 | 4.408 |
| | | $z_h$ | 1.736 | 2.315 | 2.040 | 2.060 | 2.394 | 2.109 ± 0.23 | |
| | | $x_h$ | 3.345 | 3.188 | 3.149 | 3.169 | 3.394 | 3.249 ± 0.10 | |
| | 2.92 | $y_h$ | 2.110 | 1.942 | 1.982 | 2.129 | 2.040 | 2.041 ± 0.07 | 4.445 |
| | | $z_h$ | 2.217 | 2.119 | 2.276 | 2.286 | 2.325 | 2.245 ± 0.07 | |
| | | $x_h$ | 4.670 | 4.140 | 6.622 | 4.434 | 5.817 | 5.137 ± 0.94 | |
| | 1.11 | $y_h$ | 3.188 | 2.286 | 2.786 | 2.766 | 2.629 | 2.731 ± 0.29 | 6.013 |
| | | $z_h$ | 1.295 | 1.236 | 1.236 | 1.678 | 2.158 | 1.521 ± 0.36 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $x_h$ | 5.935 | 5.906 | 5.611 | 5.759 | 5.876 | 5.817 ± 0.12 | |
| **Transportation** | 1.70 | $y_h$ | 1.972 | 2.364 | 2.129 | 2.286 | 2.335 | 2.217 ± 0.15 | 6.453 |
| | | $z_h$ | 1.324 | 1.756 | 1.717 | 1.854 | 1.844 | 1.699 ± 0.19 | |
| | | $x_h$ | 5.366 | 5.091 | 6.828 | 6.102 | 5.925 | 5.862 ± 0.61 | |
| | 2.92 | $y_h$ | 4.209 | 2.335 | 3.502 | 2.345 | 2.237 | 2.926 ± 0.79 | 6.871 |
| | | $z_h$ | 2.521 | 1.599 | 2.158 | 2.227 | 1.844 | 2.070 ± 0.32 | |

**4: YANMAR YZC-D TF110ML.**

| Operation Mode | Speed (km/hr) | Acceleration Direction | Operators | | | | | Mean Value ± Std Deviation | Vibration Total Values ($a_{hv}$ $m/s^2$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | |
| | | $x_h$ | 4.836 | 4.611 | 4.836 | 4.689 | 5.337 | 4.862 ± 0.25 | |
| | 1.04 | $y_h$ | 2.276 | 2.502 | 3.720 | 3.757 | 2.305 | 2.912 ± 0.68 | 6.012 |
| | | $z_h$ | 1.854 | 1.884 | 2.403 | 1.942 | 1.952 | 2.007 ± 0.22 | |
| | | $x_h$ | 5.740 | 6.033 | 6.916 | 5.749 | 6.141 | 6.116 ± 0.43 | |
| **Tillage** | 2.14 | $y_h$ | 3.816 | 2.904 | 3.738 | 3.777 | 3.796 | 3.606 ± 0.35 | 7.635 |
| | | $z_h$ | 3.355 | 2.266 | 2.717 | 2.296 | 3.414 | 2.809 ± 0.50 | |
| | | $x_h$ | 7.485 | 8.064 | 7.495 | 7.338 | 6.926 | 7.462 ± 0.37 | |
| | 7.14 | $y_h$ | 4.885 | 6.102 | 5.680 | 5.376 | 5.847 | 5.578 ± 0.42 | 10.263 |
| | | $z_h$ | 4.170 | 5.513 | 3.453 | 4.846 | 3.541 | 4.305 ± 0.78 | |
| | | $x_h$ | 4.042 | 4.042 | 4.326 | 4.091 | 4.552 | 4.211 ± 0.20 | |
| | 1.04 | $y_h$ | 1.864 | 1.884 | 1.854 | 1.913 | 2.080 | 1.919 ± 0.08 | 5.271 |
| | | $z_h$ | 2.619 | 2.325 | 2.619 | 2.659 | 2.394 | 2.523 ± 0.14 | |
| | | $x_h$ | 4.866 | 4.140 | 4.140 | 4.856 | 4.777 | 4.556 ± 0.34 | |
| **Rota-Puddling** | 2.14 | $y_h$ | 1.982 | 2.168 | 2.050 | 2.158 | 2.256 | 2.123 ± 0.09 | 5.606 |
| | | $z_h$ | 2.384 | 2.453 | 2.403 | 2.609 | 2.560 | 2.482 ± 0.09 | |
| | | $x_h$ | | | | | | | |
| | 7.14 | $y_h$ | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $z_h$ | | | | | | | |
| | | $x_h$ | 4.208 | 4.179 | 4.248 | 4.267 | 4.159 | 4.212 ± 0.04 | |
| | 1.04 | $y_h$ | 2.972 | 2.855 | 2.747 | 2.600 | 2.865 | 2.808 ± 0.13 | 5.622 |
| | | $z_h$ | 2.413 | 2.148 | 2.619 | 2.207 | 2.845 | 2.446 ± 0.26 | |
| | | $x_h$ | 4.679 | 3.855 | 4.189 | 4.346 | 4.787 | 4.371 ± 0.34 | |
| **Transportation** | 2.14 | $y_h$ | 3.227 | 2.521 | 2.472 | 3.178 | 2.776 | 2.835 ± 0.32 | 5.767 |
| | | $z_h$ | 2.649 | 1.923 | 2.462 | 2.610 | 2.727 | 2.474 ± 0.29 | |
| | | $x_h$ | 6.043 | 5.033 | 5.739 | 5.906 | 5.297 | 5.604 ± 0.38 | |
| | 7.14 | $y_h$ | 2.992 | 2.806 | 2.796 | 3.296 | 3.071 | 2.992 ± 0.19 | 6.903 |
| | | $z_h$ | 2.462 | 2.649 | 2.659 | 3.188 | 2.541 | 2.700 ± 0.25 | |

## C: Technical Specification for MTN/VM 110

Measurement Ranges: Acceleration: 2g, 20g and 200g

Velocity: 20mm/sec, 200mm/sec and 2000mm/sec

Displacement: 20ìm, 200ìm and 2000ìm

Frequency Range: Upper Frequency, selectable low pass filters of 5 kHz, 10 kHz, and 20 kHz

Lower Frequency fixed, Acc. 5 Hz, Vel. 10 Hz, Dis. 15 Hz

Detector: Switch selectable: RMS or Peak

Display: 12.7mm, 3½ digit LCD. 3 readings per second

Accuracy (10 mV/g Input): Figures are for the VM110 only, since input transducers will affect the overall system accuracy. All readings are ±1 digit added to the following full-scale errors.

Acc. 1.5% RMS; 3% Peak: Vel 2.5% RMS; 4% Peak: Dis 3.5%

RMS; 5% Peak (9% at 10 kHz)

Equivalent Input Noise: The equivalent input noise is the lowest measurable signal level in the range due to internally generated electrical noise.

| | RMS Noise | Peak Noise |
|---|---|---|
| Acc: | 2g range; 2mg | 6mg |
| | 20g range; 2mg | 6mg |
| | 200g range; 20mg | 60mg |
| Vel: | 0.1mm/sec | 0.3mm/sec |
| Disp: | 0.2ìm | 0.6ìm |

Inputs: Various accelerometers can be used in conjunction with the VM110. For more details contact the sales office.

Outputs: AC: 200mVac, full range as selected.

DC: 200mVdc, full range as selected.

**D: Distribution of Single-Axle Tractors in Tanzania**

| S/No. | Region | Number of Single-axle Tractors |
|---|---|---|
| 1 | Arusha | 50 |
| 2 | Coast (Pwani) | 99 |
| 3 | Dodoma | 215 |
| 4 | Dar-Es-Salaam | 7 |
| 5 | Iringa | 306 |
| 6 | Kagera | 72 |
| 7 | Kigoma | 176 |
| 8 | Kilimanjaro | 149 |
| 9 | Lindi | 332 |
| 10 | Manyara | 186 |
| 11 | Mara | 64 |
| 12 | Mbeya | 1,073 |
| 13 | Morogoro | 327 |
| 14 | Mtwara | 217 |
| 15 | Mwanza | 142 |
| 16 | Rukwa | 242 |
| 17 | Ruvuma | 314 |
| 18 | Shinyanga | 246 |
| 19 | Singida | 101 |
| 20 | Tabora | 70 |
| 21 | Tanga | 183 |
| | **Grand Total** | **4,571** |

**Source:** Department of Agricultural Mechanization, MAFC (up to June 2011).