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Original Article

Forest Management

Anthropometry Applied in Dimensioning an Earth Auger

Eduardo da Silva Lopes[1], Felipe Martins de Oliveira[1], João Fábio Machado[2], Ezaquel Bednarczuk[2], Pedro Caldas Britto[2]

[1]Departamento de Engenharia Florestal, Universidade Estadual do Centro-Oeste – UNICENTRO, Irati/PR, Brazil
[2]Programa de Pós-graduação em Ciências Florestais, Universidade Estadual do Centro-Oeste – UNICENTRO, Irati/PR, Brazil

ABSTRACT

The objective of this study was to show the application of anthropometric measurements in dimensioning an earth auger used in forest plantations, aiming to offer greater comfort, safety and health for workers. Based on anthropometric measures of a sample of 250 workers who worked on a forest implantation, seven measures in the 5, 50 and 95% percentiles obtained according to the German Standard DIN 33402/81 and related to the handling of the equipment were selected. Anthropometric standards of the workers were determined with minimum and maximum limits for the variables. Regression analyses were performed to verify the correlation between some anthropometric variables. The results show that the earth auger presented irregularities in terms of height and diameter of the handle; the measurements should range from 94 to 111 cm and 2.5 to 5.0 cm, respectively, enabling it to suit 90% of the worker population. The height showed a correlation of 68% with elbow height, and 67% with the hand center with arm hanging height.

Keywords: forest implantation, posture analysis, ergonomics.

1. INTRODUCTION

The increase in mechanization in forestry implantation activities that have been occurring in recent years has provided significant gains in terms of productivity and quality of work, as well as improvements in workers' conditions of comfort, safety and health. However, when activities are carried out in steeply sloped areas, manual and semi-mechanized methods become a viable technical and economic alternative used by forestry companies.

Among the activities widely used in these steeply sloped conditions, we can highlight pit digging, which consists of digging a hole in the soil known as a "pit". This activity can be performed using an earth auger, which is a portable machine composed of a motor, handle and drill assembly, responsible for drilling and turning the soil for subsequent planting.

Despite the technical and economic feasibility of using an earth auger in sloped areas, workers often perform the work using ergonomically inappropriate methods, adopting postures potentially harmful to their bodies, handling excessive loads and performing the work under great physical strain, in addition to being exposed to unfavorable environmental conditions (Toupin et al., 2007; Silva et al., 2007; Vosniak et al., 2010; Fiedler et al., 2011). According to Iida & Guimarães (2016), these situations can cause discomfort, compromise productivity and quality of work, as well as increase the risk of accidents and cause damage to worker's health in the future.

Among the most common ergonomic problems, inadequate posture adopted by workers stands out, which often occurs due to inadequate machinery that does not meet the anthropometric measurements for the entire user population. In this sense, Brito et al. (2011) argues that although humans are able to easily adapt to the various situations imposed by poorly designed machines and tools, these situations could adversely affect the health and safety of workers.

Anthropometry is the study of the characteristic measurements of the human body. Its main fields are the study of linear dimensions, weights, diameters, centers of gravity of the human body and its parts (Fernandes et al., 2009). Moreover, anthropometry contributes to the correction of poorly designed products in order to offer workers greater comfort, health and safety. Thus, Apud et al. (2014) affirms the importance of verifying whether machine and tool dimensions are adequate to the anthropometric measurements of the workers from a certain region, avoiding the occurrence of errors, accidents, discomfort and fatigue.

On the other hand, we must emphasize the complexity, elevated time and costs to obtain workers' anthropometric data, as well as the significant variability of the physical characteristics of the Brazilian population; situations that make it difficult to carry out reliable anthropometric surveys (Minette et al., 2002; Lopes et al., 2013; Fernandes et al., 2009). In this respect, the use of mathematical equations to estimate anthropometric variables may reduce time and costs for data collection, enabling the design or correction of work projects, machines or tools with greater speed and lower costs, and with greater ergonometric suitability for human beings (Petroski & Pires-Neto, 1995; Fonseca et al., 2007; Salem et al., 2007; Rech et al., 2012; Santos et al., 2015).

The objective of this research was to show the application of anthropometry in the correct dimensioning of an earth auger used in forest plantations, aiming to make improvements in the equipment for greater worker comfort, safety and health.

2. MATERIAL AND METHODS

2.1. Study area

This study was carried out at a service company in the forest implantation area, located in the region of Campos Gerais, in the state of Paraná, Brazil.

According to Köppen classification, the predominant climate of the study region is defined as subtropical - Cfa, with an average annual temperature in the coldest month below 18°C and average temperature in the hottest month above 22°C, with hot summers, infrequent frosts and a concentration of rain in the summer, however with no defined dry season. The terrain was classified based on the classes described by the Brazilian Agricultural Research Company - EMBRAPA (2006), as flat to strongly wavy and an average slope varying from 0 to 45%.

2.2. Study population

The study was based on anthropometric data obtained from a population of 250 male workers who were actively working in forest plantation activities, with 100% of the population in the study region being considered. The workers were informed about the methodology and objectives of the study by reading and signing the Informed Consent Form (*TCLE*), as required by Resolution 466/2012 of the National Health Council of the Ministry of Health (Brasil, 2013).

2.3. Studied Activity

Pit digging activity performed by semi-mechanized method using an earth auger or soil driller was analyzed. The machine consisted of an engine with a power of 1.3 kW (1.75 hp), 30.8 cm^3 displacement, 9.4 kg weight (without drill) and maximum rotation of 200 rpm, coupled with a helical drill bit. Figure 1 shows the main dimensions of the earth auger that are related to the anthropometric measurements and which may affect worker comfort and health.

The handle height (HH), represented by the distance between the upper end of the handle and the drill bit was 98 cm; this measurement is related to elbow height and the center of the hand with the arm hanging down (there is no standard measure for such a situation in the norm). The motor protection width (MPW) was 49 cm and was related to the width of the workers' hips in a standing position. The handle length (HL) was 12.5 cm, and is related to palm width, while the greatest diameter of the handle (ØH) was 4.5 cm and is related to maximum cylinder grip. Moreover, to better characterize the measurements of the equipment, measurements of the earth auger's height without the bit assembled (HWB), auger bit height (ABH), height of the cutting part (HCP) and drill height (DH) were taken, obtaining values of 31, 67, 42.5 and 24.5 cm, respectively.

2.4. Data collection

Workers' static anthropometric measures were initially obtained at the workplace, in positions standardized by the German Standard DIN 33402/81, and performed by the direct method using an anthropometric chair, anthropometer and tape measure, as adapted from Couto (1995). Then, six anthropometric measurements which had a direct relationship with the earth auger dimensions were selected in order to verify whether such measures of the machine were adequate for the anthropometric profile of the workers, thereby aiming to propose improvements or corrections in the machine's design.

The following anthropometric measures were considered in the study: body mass, height, elbow height, height at the center of the hands with the arm hanging down, hip width, palm width and maximum cylinder grip, as shown in Figure 2 where: a = height; b = elbow height; c = height at the center of the hands with the arm hanging down; d = hip width; e = palm width; f = maximum cylinder grip.

The anthropometric variables of the workers were analyzed using percentiles, which divide the disqualification of frequency into one hundred equal parts; 5, 50 and 95% percentiles were used to account

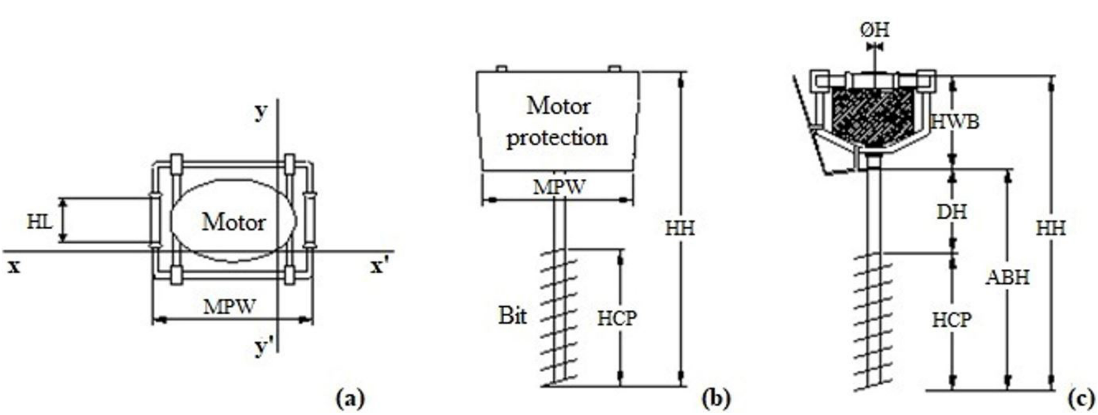

Figure 1. Dimensions of the earth auger from the top view (a) and the sections xx' (b) and yy' (c). HL = handle length (12.5 cm); MPW = motor protection width (49 cm); HH = handle height (98 cm); ØH = greatest diameter of the handle (4.5 cm); ABH = auger bit height (67 cm); HWB = height of the earth auger without the bit assembled (31 cm); HCP = height of the cutting part (42.5 cm); DH = drill height (24.5 cm). Source: Adaptaded from Iida & Guimarães (2016).

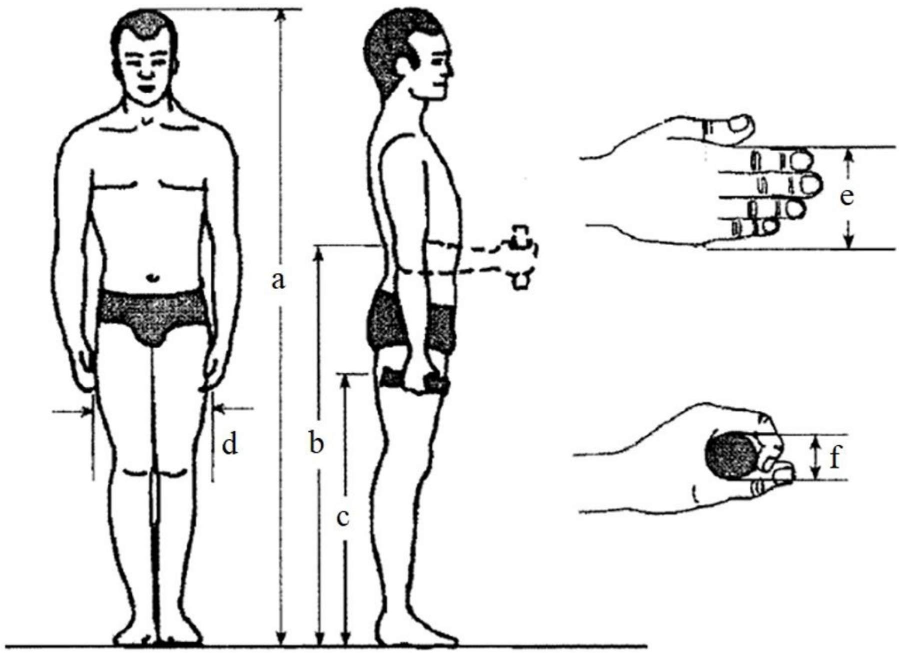

Figure 2. Illustration of the anthropometric measures of the studied workers.

for 90% of the population, and standard deviation and coefficient of variation of the data were also determined.

Linear regression equations were also adjusted to estimate some anthropometric variables of the workers (dependent) according to their height and body mass (independent), through the proposed models (1), (2) and (3).

$$Y = \beta 0 + \beta 1X1 \quad (1)$$

$$Y = \beta 0 + \beta 1X2 \quad (2)$$

$$Y = \beta 0 + \beta 1X1 + \beta 2X2 \quad (3)$$

Where: Y = Anthropometric variable; β = Estimation parameters; X1 = Height; and X2 = Body Mass.

The Pearson correlation coefficient (r), the adjusted coefficient of determination (adjusted R^2), the default percentage error (Syx%) and graphical analysis were used for the adjustment evaluation.

3. RESULTS AND DISCUSSION

3.1. Analysis of earth auger dimensions

Workers' static anthropometric measures that related to the earth auger's dimensions can be seen in Table 1. Height and body mass were used to identify the workers' profile and help define the parameters for resizing earth augers. It is important to emphasize the low coefficients of variation obtained in all observed variables, indicating the homogeneity of the sample.

As can be observed, the workers had a mean (body) height of 167.2 ± 6.4 cm and average body mass of 69.8 ± 10.3 kg, with a variation in the (body) height between 156.8 and 178.5 cm and in body mass between 54.9 to 85.2 kg in the 5 and 95% percentiles, comprising 90% of the workers studied. Minette et al. (2002), found an average (body) height of 171.0 cm and body mass of 67.9 kg when studying chainsaw operators in the state of São Paulo, while Silveira (2006), found an average (body) height of 170.0 cm and body mass of 68.8 kg when studying forestry workers.

It is important to emphasize that the earth auger height must be analyzed according to its minimum and maximum standards in order to include the majority of workers, meaning the tallest and shortest. This is similar to the study by Britto et al. (2014), which showed more severe working conditions for workers in the lowest (5%) and highest (95%) height percentiles. Therefore, the minimum height dimensioning should be based on the 5% percentile for the elbow height variable with the forearm at approximately 90° from the surface level, since it is from this height that the worker moves to

Table 1. Anthropometric measures of workers in the 5, 50 and 95% percentiles and dimensions related to the earth auger.

Anthropometric measure	Dimensions related to the earth auger	Percentile (%)			Mean	SD	CV (%)
		5	50	95			
Height (cm)	-	156.8	167.0	178.5	167.2	6.4	4
Body mass (kg)	-	54.9	68.7	85.2	69.8	10.3	7
Elbow height (cm)	Handle height	94.0	102.2	111.0	102.1	5.0	5
Height at the center of the hand, arm hanging down (cm)	Handle height	68.1	75.0	81.2	75.0	4.3	6
Hip width standing (cm)	Motor protection width	26.7	30.2	34.2	30.6	2.4	8
Palm width (cm)	Length of the handles	7.6	9.0	10.0	8.9	0.7	8
Maximum cylinder grip (cm)	Diameter of the handles	2.5	4.0	5.0	3.8	0.7	8

SD = Standard deviation; CV = Coefficient of variation.

start a new digging cycle while holding the machine in their hands.

However, as the earth auger presented a height of 98 cm, and elbow height in the 5% percentile was 94 cm, we can affirm that the minimum height of the machine attends to a small number of the sampled workers. For workers with an elbow height above this percentile, posture becomes inadequate, making the activity uncomfortable and having an increased risk of spinal injuries and health problems. Moreover, since the 95% percentile was 111 cm, it is suggested that the earth auger has a height regulation ranging from 94 to 111 cm to serve 90% of the worker population.

Understanding this type of effort is very important, given that Minette et al. (2010) demonstrated that 99% of the workers involved in the pit digging activity presented risks of injury to the elbow joint and to the lumbar - 5 sacral - 1 intervertebral disc (L5-S1) of the spine when performing work with a hydraulic earth auger prototype during pit digging. Additionally, Lopes & Oliveira (2011) report that the continuous movement of workloads contributes to the occurrence of lower back pain.

Fiedler et al. (2011) studied semi-mechanized (pit) digging, and verified harmful postures during more than 50% of the operational time, characterized by a combination of inclined backs under the weight of a 10 - 20 kg load and fatiguing leg posture, a situation that can cause serious problems to workers' spines. Silva et al. (2007) also verified serious situations for workers' health in semi-mechanized (pit) digging, with overloading of the spine (between lumbar 5 and sacral 1 vertebra) while working. Vosniak et al. (2010) found damaging positions during this same operation attributed to a lack of options for adjusting or regulating the earth auger, which led to workers of different heights adopting inadequate postures. Therefore, the need to readjust the earth auger's dimensions to meet the anthropometric measures of the workers and prevent them from assuming inadequate postures and compromising their spine is evident.

The amplitude obtained for the height variable was 21.7 cm, which was close to the amplitude for the elbow height variable (17 cm). Therefore, the development of a regulation system to adjust the earth auger's height between the 5% and 95% percentiles to satisfy those two anthropometric variables is recommended.

In order to verify the level of force applied on the worker's spine when the drill is inserted into the ground, the difference between the elbow height and that of the center of the hand with the arm hanging down were analyzed. As the difference between the two variables was 25.9 cm in the 5% percentile and 29.8 cm in the 95% percentile, we can affirm that the measure was satisfactory for 90% of the workers when the pit depth was over 25.9 cm, therefore causing strain on the workers' backs.

Motor protection width was 49 cm; its dimension was related to the standing hip width variable, presenting 34.2 cm in the 95% percentile. This demonstrated that the needs of 95% of the worker population were being met with no need to change the machinery. The handle length (12.5 cm) served the majority of workers, considering that the variable palm width presented 10.0 cm in the 95% percentile. Therefore, a longer handle than necessary would provide more comfortable working conditions, taking care not to have a larger/exaggerated size which could lead to an increase in project costs and impair machine handling when performing the work.

It is important to point out that the earth auger handle had an ellipsoidal shape, in which the largest diameter was 4.5 cm in the 5% percentile. In relation to the maximum cylinder grip, this measure was adequate for 95% of the workers. The 5% percentile of this variable corresponded to 2.5 cm, below the diameter of the handle, suggesting the need for a diameter between 2.5 and 5.0 cm, thereby attending to 90% of the workers.

Therefore, we can observe the importance of performing dynamic anthropometric measurements, given that in practice the workers perform this work using continuous and repetitive movements. Moreover, machines or tools with dimensions that do not match anthropometric measures of users may compromise their comfort, productivity, safety and health.

3.2. Estimates of anthropometric measurements

The results of the correlation analyses between the anthropometric variables are presented in Table 2, showing the behavior of the equations for each distinct and simultaneous predictor variable. The residual graphs containing estimated ($\hat{Y}$) and observed (Y) values for the anthropometric variables are shown in Figure 3.

Height was the variable that best represented elbow height and the height of the center of the hand with the arm hanging down, which can be used in practical terms for dimensioning and adjusting the equipment height. On the other hand, body mass was better related to the width of the hips and can be used as a reference for dimensioning the minimum width for the handle location.

The best fit was obtained by model (3) applied to the variable of height at the center of the hand with the arm hanging down, explained by body height and body mass of the individual with a correlation coefficient of 0.69 and adjusted R^2 of 0.47. The equation adjusted by model (1), considering only the predictor variable of (body) height presented a correlation coefficient of 0.67, adjusted R^2 of 0.46 and standard error percentage of 4.17%.

Another anthropometric variable that presented similar results was elbow height in the Model (3). When compared to Model (1), the same r value was obtained with adjusted R^2 one tenth lower and standard error 0.01% greater, showing that body mass explained very little in relation to elbow height behavior, with a low correlation between both variables. It is also important to highlight the adjustments made to the standing hip width variable provided by the models (3) and (2).

The other variables did not present adequate adjustments which can be explained by the limited

Table 2. Equations for the estimation of some anthropometric variables as a function of (body) height and body mass.

Anthropometric variable (Y)	Equation	R	R^2 adj.	Syx (%)
Elbow height (cm)	(1) Y = 6.0634 + 0.5793 × H	0.68	0.45	3.63
	(2) Y = 95.1569 + 0.111 × BM	0.31	0.09	4.68
	(3) Y = 5.4521 + 0.5924 x H – 0.0226 × BM	0.68	0.46	3.62
Height at the center of the hand, arm hanging down (cm)	(4) Y = - 0.2730 + 0.4503 × H	0.67	0.46	4.17
	(5) Y = 64.8825 + 0.145 × BM	0.35	0.12	5.32
	(6) Y = 1.077 + 0.4214 × H + 0.05 × BM	0.69	0.47	4.13
Hip width standing (cm)	(7) Y = 9.1374 + 0.1263 × H	0.34	0.11	7.33
	(8) Y = 20.535 + 0.1394 × BM	0.61	0.36	6.21
	(9) Y = 12.5819 + 0.0525 × H + 0.1275 × BM	0.62	0.38	6.13
Palm width (cm)	(10) Y = 4.6102 + 0.0257 × H	0.23	0.05	7.83
	(11) Y = 7.6805 + 0.0177 × BM	0.25	0.06	7.78
	(12) Y = 4.979 + 0.0178 × H + 0.0137 × BM	0.29	0.08	7.71
Maximum cylinder grip (cm)	(13) Y = 1.2677 + 0.0153 × H	0.14	0.02	17.58
	(14) Y = 3.802 + 0.0003 × BM	0.01	0.01	17.77
	(15) Y = 1.1696 + 0.0174 × H – 0.0036 × BM	0.15	0.02	17.60

Y = Answer variable; H = (Body) height (cm); BM = Body mass (kg).

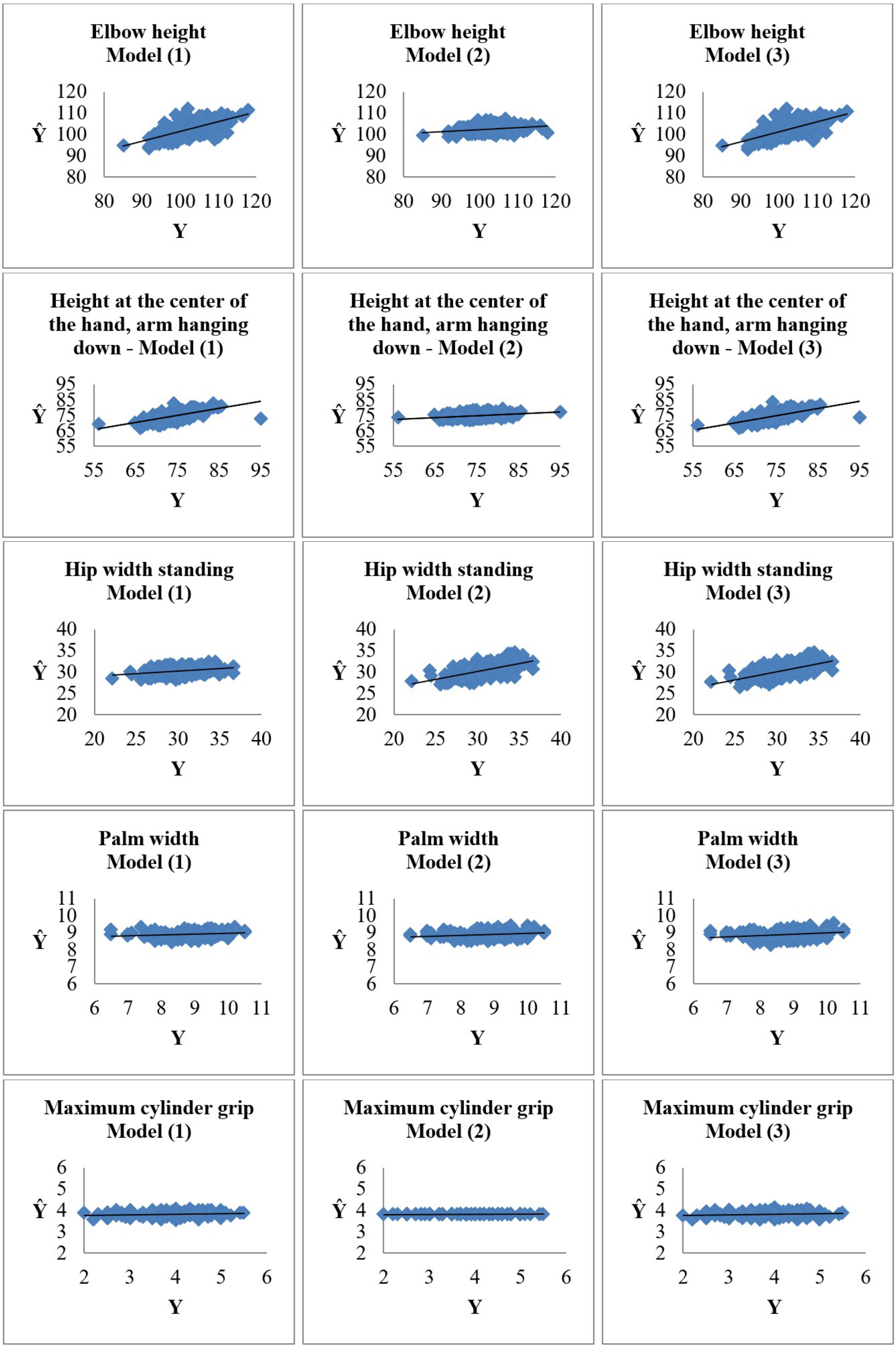

Figure 3. Estimated and observed values for the anthropometric variables.

number of predictor variables. It is important to emphasize that complex models that make collecting independent variables difficult are not desired, since the applicability of the equations is related to their ease of use in the daily routine of the forestry sector.

The graphical analysis allowed us to observe biases, however, it is not as effective when the models present a very similar performance, which demonstrates the difficulty to evaluate the figures due to their subjectivity (Silva et al., 2011). Nevertheless, the graphs for palm width and maximum cylinder grip variables showed the difficulty to estimate their values based on both body height and mass.

4. CONCLUSIONS

- The anthropometric measures were adequate to indicate the need for adjustments in earth augers mainly in terms of drill height and handle diameter measurements, with it being recommended that they be adjustable to facilitate better machine adaptation to the anthropometric characteristics of the workers;
- Body height was the anthropometric measure that best represented the elbow height and height of the center of the hand with the arm hanging, and can be used in practice for the dimensioning and adjustment of the equipment;
- The anthropometric measures can be used as references for the development of projects with adjustable forestry machinery and equipment, which can contribute to improving the work place health and safety conditions of workers.

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CORRESPONDENCE TO

Eduardo da Silva Lopes
Departamento de Engenharia Florestal, Universidade Estadual do Centro-Oeste - UNICENTRO, BR 153, Km 7, CEP 84540-000, Riozinho, Irati, PR, Brazil
e-mail: eslopes@unicentro.br

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