Conceptual Design Knapsack Sprayer for Palm Oil Cultivation by Ergonomic Approach

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Abstract— Designing a tool/machine needs ergonomics approach in order to match between man-machine system. One of the important tools in oil palm cultivation is knapsack sprayer. This study was conducted in aiming to understand occupational risk on the knapsack sprayer operation. So, ergonomic analysis is needed for these activities to understand the need of intervention to reduce the risks of working and complaints that occur. Based on Nordic Body Map questionnaire, the operator of knapsack sprayer suffered musclular fatigue and pain on the leg (28%), the upper arm left (27%) and the neck (14%). Based on Range of Motion's criteria, dangerous zone (Zone 3) are the flexion of hip, shoulder, and neck. Futhermore, REBA method was applied to evaluate work posture in detail. The REBA revealed that score of 8 or more were resulted on "Loading", "Pumping" and "Spraying" work elements. These mean that work elements were high level of MSD's risk thus changing in the working condition is needed soon. Workload analysis found that 17 kg of total weight knapsack sprayer with the dimension of knapsacks sprayer's tank is (390 x 171 x 534) mm. Recommanded resting time for *knapsack sprayer* operator is 125 minutes for 4 hours working time.

Index Terms— sprayer**,** nordic, rom, reba, workload.

1 INTRODUCTION

Occupational health and safety assessment is one of important thing to prevent work accident that could be happen. The labour should pay attention occupational health and safety factor and make sure working condition securely so that it could enhance work productivity of the labour. Process oil palm cultivation has a lot of dangerous occupational risk so that it could cause work accident on the labour. According to BPS (2010), total of oil palm production in 2009 is 13.872.602 tons then the increasing of oil palm in 2010 is 14.038.148 tons [4]. It followed by the increasing of total labour in process oil palm cultivation is approximately 5.005.412 workers.

The number of work accident that could be happen in the oil palm industry could affect oil palm industry's images. It will impact the competitiveness of the oil palm industry in market. Working activity of oil palm industry especially oil palm cultivating maintenance in Indonesia still rely on manual labour. Conceptual design should comprehend in limitation of workload worker so that it could reduce fatigue in musculoskeletal systems.

Knapsack sprayer operation certainly has potency on occupatinal health and safety problems, such as muscle pain is caused by sprain/dislocate because of lifting overload, repetitive motion and awkward posture. Knapsack sprayer operations use in oil palm plantation area that are very varied situations and topographical conditions exist in the form of flat, swamps, and hilly land. If the workers do not pay attention safety factor and correct procedure in using knapsack sprayer, it would cause various risk that have fatal consequences.

Ergonomic approach needs in designing a tool/machine in order to match between man-machine system. Designing a knapsack sprayer is important to appropriate movements efficiently in order to minimize fatigue or pain. In consequence, it needs redesign or subtitute tools/workstation. This study was conducted in aiming to understand occupational risk on the knapsack sprayer operation and redesign knapsack sprayer through ergonomic approach.

2 RESEARCH METHOD

2.1 Time and Location

Research was carried out from February to July 2015. Observation of knapsack sprayer operation undertaken in Researching and Teaching Oil Palm Plantation – Bogor Agricultural University. Subject consist of five knapsack sprayer's operator. The numbers of sampled-subjects were selected all of available workers in study area.

2.2 Material and Equipment

A portable weighing scale with an accuracy of 0.1 kg measured the body weight and digital camera analyzed work posture. A computer recorded the collected data and a common spreadsheet was used to analyse them.

2.3 Research Procedure

The procedures of data collection were explained to the subject before starting the measurement to obtain their understanding and cooperation Research's procedures consist of 4 stage. First, preliminary stage was learning about enviroment, culture and working condition in study area. Then, the knapsack sprayer operation was observed with digital camera in aiming to find out duration of the working time knapsack sprayer operation.

Second stage was collecting data. Not only quantative data but also qualitative data was undertaken in this study. Quantative data was recording data on knapsack sprayer operation, antropometric data (stature and body weight) and knapsack sprayer actual dimension meanwhile qualitative data was questionnaire data that be given for subject.

Third stage was analysis data that used to cognize workload parameters so that it will be made reference for design recommendation through ergonomic approach (Nordic Body Map questionnaire, Range of Motion, Rapid Entire Body Assessment and Total Energy Expenditure). Nordic Body Map

questionnaire was used to understand complaint that occur on the subjet. Then, Range of Motion method was used to predict occupational risk movements when using knapsack sprayer. After that, Rapid Entire Body Assessment method was conducted to evaluate work posture in detail. Last method, Total Energy Expenditure (TEE) was used to assign schedule of working time and resting time using Muller equation (1965). This TEE analysis used reference data for Work Energy Cost (WEC) using SNI 7269:2009. Then, calculation of Basal Metabolic Energy (BME) used Du Bois equation [15].
Fouth, conceptual design stage was modifacation of knapsack sprayer components after understanding interaction between man-machine with complaint that occur. This stage covered find out alternative design based on criteria design that had analyzed through ergonomic approach. Beside that, it determined recommendation of working procedure (the ammount of workload, working time and resting time).

3 Results and Discussions

Designing a tool/machine requires represen-tative data to determine criteria design based on user's needs. The results of design sometimes do not fulfill user's needs because design engineer is hard to get representative data [10]. Incompatibi-lity an engineering design that not based human center design would cause musculoskeletal trauma complaint on the knapsack sprayer's operator. Ergonomic approach that is used to determine good design needs ideal working posture in order to knapsack sprayer operator do not suffered risk injury in working condition.

Oil palm plantation that is categorized Tanaman Belum Menghasilkan (TBM) in this study is approximately 73.4 Ha.

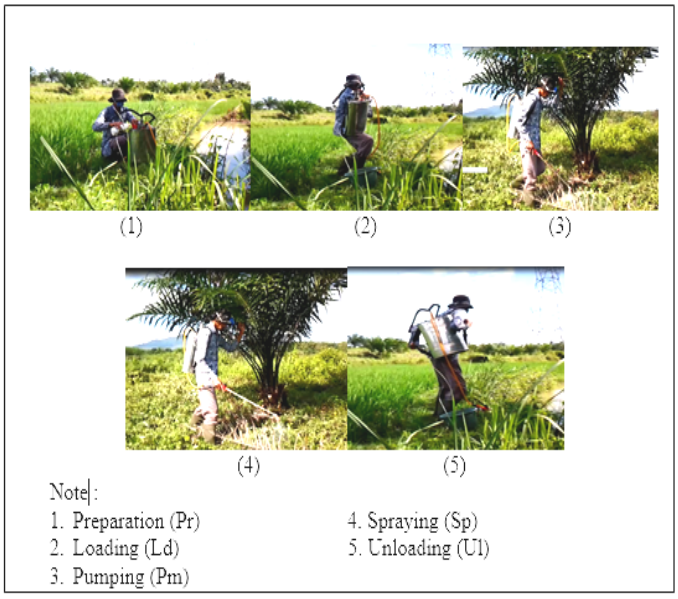

Fig. 1. Work Element of Knapsack Sprayer Operation

Herbicide spraying activity aims to eradicate weeds on around oil palm trees. Knapsack sprayer of operators work during 4 hours from 08.00 pm to 12.00 pm. Type of knapsack sprayer in this study use piston-pump over arm. Total workburden's operator is 19 kg (5 kg of empety weight tank). Recording video divided into five work elements (Figure 1).

3.1 Nordic Body Map

Operators suffered Musculoskeletal Disoders (MSDs) on the left shoulder (28%). This is related to the pumping motion repeatedly 11 to 15 times/minute so piston puts pressure for pushing the herbicide fluid to hose tube before breaking granular fluid through nozzel. Another cause of complaints on the shoulder is static loading by carrying belt (straps) therefore bring a blockage of blood flow in the muscle. Supplying shortages of blood flow in the muscle would cause a decreasing ability of muscle contraction. If this situation are in long term, it would lead to MSDs risk. Straps material used in synthetic ruber with low elasticity so that it could not breakdown the forces distribution on the shoulder as a result of load sprayer accumulation.

Other complaints suffered by the operator using Nordic Body Map questionnaire was lower limb (27%). Lower limbs occur static and dynamic loading during knapsack sprayer operation. Static loading is affected by total of operator weight themselves and knapsack sprayer weight. The amount of workload that could be lifted, is acceptable with physical characteristic operator. If they take overexertion load, it would cause MSDs risk. Meanwhile, dynamic loading is related to working motion during knapsack sprayer operation. They refill herbicide solution four – eight times/day.

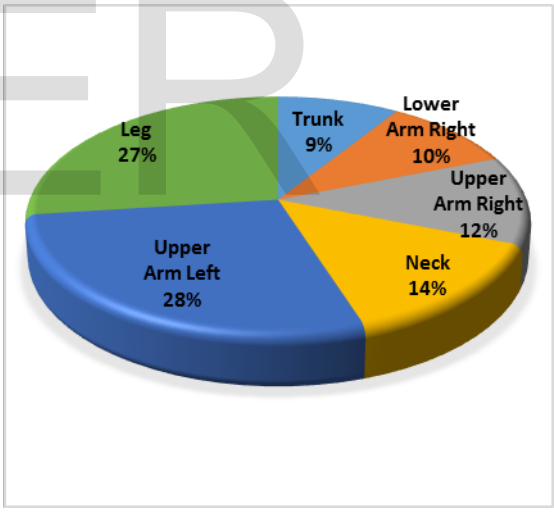

Fig. 2. Muscular fatigue and pain complaints

3.2 Range of Motion (ROM)

Work element was analyzed using Range of Motion (ROM) in order to predict occupational risk on the knapsack sprayer operation. The working motion needs conformity with ROM's criteria. Openshaw [13] recommend that operator should minimize working motion on Zone 2 and Zone 3 but should maximize joint movements on Zone 0 and Zone 1 . Based on ROM criteria, parts of body that were resulted in interval motion on dangerous zone were the flexion of elbow,

TABLE 1
MAXIMUM KNAPSACK SPRAYER WORK MOTION

Work element	Nf	Ne	Sf		Se		Ef		Tf	Hf		Kf	
			R	L	R	L	R	L		R	L	R	L
Preparation	12		29	41			128	141	11	101	113	134	126
Loading	8		36	57			169	139	17	71	41	81	108
Pumping	51		52	118			49	45	22	57	19	35	34
Spraying	35		11	21			35	51	12	11	16	30	17
Unloading	11				11	47	131	41	8	22	14	40	47

Note :
Nf = Neck Flexion Ef = Elbow Flexion
Ne= Neck Extension Tf = Trunk Fleksion
Sf = Shoulder Flexion Hf = Hip Flexion
Se = Shoulder Extension Kf = Knee Flexion

Zone 0/neutral zone
Zone 1/safe zone
Zone 2/ warning zone
Zone 3/dangerous zone

hip and knee on the Preparation (Pr) and Loading (Ld) work elements. These work elements should be done quickly as soon as possible so that avoiding MSDs risk. Neck position on Pm work element was included in Zone 3 because neck flexion angle are more 51°.

Neck flexion condition associated with eye viewpoint to find out weeds spraying area. The left shoulders on the Pm work element also were in Zone 3 because of 118° extenion angle. Openshaw [13] stated that the movement in Zone 2 and 3 experienced excessive contraction of the muscles and tendons.The position of the body in Zone 2 and Zone 3 should be minimize, especially on repetitive motion and overload workburden.

3.3 Rapid Entire Body Assessment (REBA)

REBA method was conducted in aiming to evaluate work posture in detail. There are three main movement of knapsack

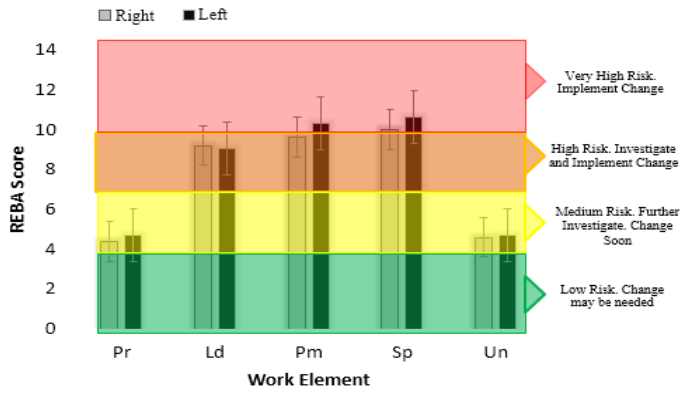

Fig. 3. REBA score of knapsack sprayer operation

sprayer operation i.e (1) lifting movement of the piston pump, which is picked up pump up the maximum range,(2) the movement of pressing piston pump handle and (3) movement of the piston presses with maximum traction. Each work element was analyzed posture assessment that can be found occupational risk magnitude on the knapsack sprayer operators.

Figure 3 show that the results of average REBA score on work elements of Pumping (Pm) and Spraying (Sp) were score of 7 or more. Thus, the work elements had high risk level of MSDs and need interventions to change working conditions. Left hand on Pm work element had a REBA score of 10 because shoulder flexion position was 118°. Left upper arm had a REBA score of 4 then forcing shoulder to contract muscles higher in flexion.

Rating scores are influenced by shoulder muscles work force against gravity and mass grip the pump. If left upper arm movements is done repeatedly, it would cause interference on the musculoskeletal system. The greater angle of upper arm flexion so that operator would suffer a faster rate of fatigue [3]. Left arm characteristic motion was associated with MSDs high risk level so that required modification pumping handle design.

3.4 Total Energy Expenditure (TEE)

Total Energy Expenditure (TEE) was used to estimate metabolic energy amount on workload capacity for each subject. Workburden total that is carried by operator is 19 kg with 4 hours working time. Lowest energy expenditure operator reached 6.99 kcal / min. Work energy cost data is not measurements in this study but it used reference data according to SNI 7269: 2009 concerning the workload.

A workload level could be influenced by several factors, including : body weight, load, gender, working time and lifting frequency. It is required arrangement of working time and rest periods. Relationship between the average working energy consumption (Table 3) is proportional to rest periods in the activities of knapsack sprayer operations. Muscles overexertion that work will affect the occurrence of fatigue and inflammation in muscles and joints. If high work frequency and less rest periods, it would cause to lead a level of severe cumulative trauma disorders, such as tendonitis. Based on equation Muller [8] determined rest period requirement range from 123 – 126 minutes.

Operators tendency who do not meet recovery time would affect the declining of labor productivity in the spraying activities. In biochemistry decreasing ability of muscle work due to lactic acid formation as a result of changing ATP to ADP without oxygen assistance. Thus, there is no oxygen supply needed to perform a muscle contraction.

TABLE 2
TOTAL ENERGY EXPENDITURE

Subject	Weight (kg)	Stature (cm)	Age	Index body surface area	VO_2 (ml/ minute)	BMR (kcal/minute)	Work Energy (kcal/minute)	Total Energy Expenditure (kcal/minute)
A1	54	172	31	1.65	204	1.02	6.05	7.07
A2	44	170	29	1.50	187	0.94	6.05	6.99
A3	61	168	34	1.71	212	1.06	6.05	7.11
A4	43	164	24	1.45	179	0.90	6.05	6.95
A5	57	174	28	1.70	210	1.05	6.05	7.10

TABLE 3
REST PERIODS REQUIREMENTS

Subject	Total of working time (minute)	TEE (kcal/minute)	Standard normal workload (kcal/minute)	Rest periods (minute)
A4	240	6.95	4	123
A2	240	6.99	4	124
A4	240	7.07	4	126
A5	240	7.1	4	126
A1	240	7.11	4	126

3.5 Knapsack sprayer operation ergonomic assessment

Ergonomics assessment criteria consist of working posture and workload analysis. The analysis data stage (both subjectively and factual perception in the field) stated that knapsack sprayer usage does not meet the ergonomics criteria. Operator subjective perception (Nordic Body Map questionnaire) were verified by working posture analysis (ROM and REBA).

Based on Nordic Body Map analysis, operator suffered severe complaints on lower limb. In addition, Left arm movement was not optimal working posture. ROM stated work elements of Pr, Ld, and Pm were not ergonomic working conditon while REBA analysis revealed that work elements of Ld, Pm and Sp were not fit ergonomics criteria. This result is due to differences in ROM method does not take into account the amount of load weight, the level of lifting ease and acceptable lifting duration. ROM methods are classified by joint movements [13].

On the other hand, REBA method analyze working posture in detail by taking into account the amount of load, coupling scores and scores activity. Work elements of Ld and Pm were not meet the working postures ergonomically. Therefore it can be concluded in accordance with the subjective perception operator and posture analysis work that has been done.

Knapsack sprayer usage also was reviewed by workload analysis. It can be indicated that knapsack sprayer operation was ergonomic yet.

Observations in the field revealed that knapsack sprayer operators did not pay attention to working time and rest periods carefully. TEE approach performed to predict the length of working time and rest periods required. Scheduling of working time and rest periods needed to avoid going on operator fatigue. High fatigue levels that occurred on the operator would cause a decreasing ability of muscle contraction. It would also affect results of spraying herbicides uniformity.

3.6 Knapsack sprayer conceptual design

Kinoshita [7] states that limit load could be accepted by the operator is 30% of the total body weight. Thus, load that can be tolerated by using a percentile 50th West Java, Indonesia anthropometric data [15] is 17 kg. Therefore dimensional knapsack sprayer could be determined by comparison of 14 kg for the herbicide solution and 3 kg for the mass knapsack sprayer (tank empty).

Total volume = 0.014 m^3 = 14 x 10^6 mm^3
Volume total = volume larutan x correction factor (Cf)

= 14 x 10^6 mm^3 x 2.54
= 35.56 x 10^6 mm^3

Tank width = chest (bust) depth percentil 5
= 171 mm

Tank length = shoulder breadth percentil 5
= 390 mm

Tank height = 35.56 x 10^6 mm^3/ (171 mm x 390 mm)
= 534 mm

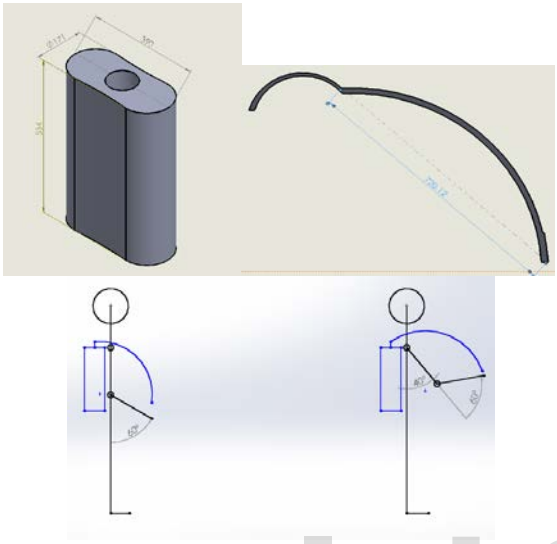

Fig. 4. Schematic knapsack sprayer conceptual design

3.7 Ergonomic risk management procedure

The human body has physical limitations to make the system workload safe. Work procedures with a focus on ergonomics program needed to prevent injury complaints and disease by controlling and reducing working system inefficiently.

3.7.1 Tank position knapsack sprayer

Rostykus et al. [14] identified five responses in improvement of working procedures: (1) performing treatment on the injured operator, (2) adjusting the operator physical characteristics with the task, (3) replacing new operator, (4) conducting work training to improve the work system more effective and (5) changing working method. Knapsack sprayer position usage is on the operator upper back. Stuempfle et al (2004) state that high position at the back were able to reduce the oxygen consumption by 16.2% than in the low position. It is influenced by longsleeve straps are relatively closer to the shoulder so that the moment of force generated becomes smaller.

3.7.2 Working time and rest periods arrangement

Based on workload analysis, it requires setting the working procedure. Therefore, operators need a recovery time ranges from 125 minutes in order to avoid musculoskeletal injury potency during the 4-hour working time of knapsack sprayer operation. Working pattern of knapsack sprayer operation is one hour of working time and 30 minutes of rest periods. If the recovery time is fit in ergonomic approach then operator fatigue level could be reduced during on spraying activities. In addition, start of working hours at 07.00 due to the working environment temperature has not reached the maximum point which would affect the level of operator fatigue.

4 CONCLUSION

1. Work motion risk level knapsack sprayer operation using a subjective perception (Nordic Body Map questionnaires) stated MSDs complaints were lower limb 28%, left upper arm 27%, and neck 14. Based on ROM criteria, Dangerous zone (Zone 3) were in flexion of hip, shoulder, and neck.
2. Evaluation ergonomics through work posture using REBA revealed that working elements of Ld, Sp and Pm had a score 7 or more so that it was high risk and required changes in working conditions.
3. Recommended operator loading limit is 17 kg. Rest periods required 125 minutes for 4 hours efective working time.
4. Knapsack sprayer tank dimensions recommendation of (390 x 171 x 534) mm with 720 mm length of 720 tank pump lever.

REFERENCES

[1] [BSN] Badan Standardisasi Nasional. 2009. Penilaian beban kerja berdasarkan tingkat kalori menurut pengeluaran energi. Jakarta (ID) : BSN.

[2] Chaffin DB, Anderson GBJ. 1991. *Occupational Biomechanics*. New York (US) : John Wiley and Sons Press.

[3] [Ditjebun] Direktorat Jendral Perkebunan. 2012. Produksi komoditas tanaman perkebunan angka estimasi. Jakarta (ID) : Ditjebun.

[4] Grandjean E. 1982. *Fitting The Task To The Man* : *an Ergonomic Approach*. London (GB) : Taylor & Francis Inc.

[5] Hanani I. 2012. Studi antropometri petani dan aplikasinya pada penggunaan *knapsack sprayer* di Kecamatan Wedung Kabupaten Demak Jawa Tengah [skripsi]. Bogor (ID) : Institut Pertanian Bogor.

[6] Hignett, McAtamney. 2000. Rapid Entire Body Assessment (REBA), *Applied Ergonomics* 31 (2000) 201-205.

[7] Kinoshita. 1985. Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Journal of Ergonomics*. 28 (9) : 151 - 162.

[8] Muller EA. 1965. Physiology methods of increasing hu man physical capacity work. *Ergonomics*. 40 (9) : 430 - 445

[9] Nugrahaning SD. 2014. Desain model diagnostik resiko ergonomi pada pemanenan kelapa sawit secara manual [skripsi]. Bogor (ID) : Institut Pertanian Bogor.

[10] Rouse WB dan Boff KR .1998. Packaging human factors for designer : Ergonomics in Design. *Applied Ergonomics*. 6 (1) : 11-17

[11] Openshaw. 2006. *Ergonomics and Design A Reference Guide*. Iowa (US) : Allsteel Inc.

[12] Rainbird. 1995. Occupational disorders affecting agricultural worker in tropical develpoping countries. *Applied Ergonomics*. 26 (3) : 187-193.

[13] Rostykus et al. 2013. Musculoskeletal disorders: five common management approaches. Professional safety. *Journal of Ergonomics*. 58 (1) : 35- 42.

[14] Stuempfle et al .2004. Effect of load position on physiological and perceptual responses during load carriage with an internal frame backpack. *Ergonomics*. 47 (7) : 784-789.

[15] Syuaib MF. 2015. Anthropometric study of farm workers on Java Island, Indonesia, and its implications for the design of farm tools and equipment. *Applied Ergonomics*. 51 (2015) : 222-235.