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3-D-Motion Analysis as a Tool for Objective Evaluation of Manual Work Processes

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Summary

The reduction of labour costs as well as the improvement of the work situation are future goals for the horticultural sector. Hence it is necessary to objectively evaluate existing and new work systems, but so far an appropriate method regarding economic and ergonomic criteria is lacking. The study of human motions seems promising. The necessary effort concerning time and motion to fulfil a work task can be described by motion data, and in consequence a 3-D-motion analysis system in combination with an analysing software is used to gain complex information about different work processes. The digital recording of the motion data allows a large sample size and hence is an excellent basis for statistics. The wide range of descriptive parameters gained in one experiment allows a better data interpretation compared to existing methods for rationalization or ergonomic evaluation.

Two different experimental settings are described to point out the wide range of application and the combined consideration of ergonomic and economic measures. In experiment 1 the influence of varying machine parameters on human performance is investigated. The determined variation within the performance data is explained by further interpretation of the motion data. Similar to the idea of the REFA performance rate, inter-personal variation plays an important role for the comparison of data and is explained by descriptive parameters like speed of movement, movement efficiency or targeted precision.

In experiment 2 the emphasis is put on ergonomics, evaluating an unusual seated work place that differs from ordinary table-stool-systems. Due to the unusual setting there exist no applicable ergonomic workplace recommendations and in consequence new indicators have to be defined. Quantitative differences between the two seat constructions are presented and allow a final judgment.

Key words. motion analysis – objective evaluation – ergonomics

Introduction

Despite a fast technical progress, satisfactory equipment for mechanization of many tasks within horticultural production is still lacking, leaving a high percentage of hand-work. Manual work in agricultural work systems is often coupled with ergonomic hazards like awkward working postures, long duration exertions, lifting and carrying of heavy loads and in consequence can cause work-related injuries. Based on European surveys, 48 % of the employees in the horticultural branch suffer from muscular-skeletal disorders (Mohr 1998). In 2001, 1.62 million days of absenteeism were counted in the German forestry and agricultural sector, causing a production loss of 90 million Euros (BauA 2001).

The working conditions of seasonal migrant workers in agriculture are characterized by "salaries close to the legal minimum, inadequate health and safety conditions, approximate calculations of working hours" (Icftu 2003). Seasonal workers play an important role in horticultural production.

The competition between sellers for horticultural products on the world-market requires a constant reduction of production costs. A more efficient implementation of manpower could help to reduce labour costs. An increased attractiveness of simple manual tasks is also desired in order to be able to recruit seasonal workers from local labour-markets. To solve these problems the consideration of economics and human factors at the same time is necessary. The design of such systems requires a method to objectively evaluate present and new work systems regarding their complexity and the high variation of influencing factors within horticultural production. The application of existing methods, like MTM (Refa 1992) or OWAS (Kahru et al. 1977) is often limited to single aspects like solely dealing with time expenditure or regarding body postures. For a combination of different methods data synchronization is necessary.

A holistic method that measures economic and ergonomic parameters at the same time has not been introduced in agricultural work science yet.

Ergonomic interventions to remedy the bent and stoop postures in agriculture go back to the 1960's (Meyer 2004), when prone workstations were invented. The most popular application of prone platforms is the selective cucumber harvest. Rullmann and Kleisinger (2003) redesigned the platform creating individually adjustable sloped and segmented body supports. The improvement

was testified by EMG studies of the middle and lower trapezium muscle groups.

There also exist human-powered prone carts used for the harvest of products at ground level. MATTILA (2001) investigated different methods (traditional, knee-stool, milking stool, sit-down cart, prone cart) to improve the strawberry harvest. Subjective strain assessment and the measurement of the heart rate both favoured the prone cart.

Alternative methods of reducing stress on low back while working in stooped postures were evaluated by BARRETT and FATHALLAH (2001), being rated uncomfortable by agricultural workers.

The attempt to use the computer based human model RAMSIS was carried out in the 90's at the TU Munich (MESSERSCHMIDT 1993). The limitations of these models became obvious, their application being only successful within the defined domain they are designed for, like a cockpit of a car.

During two harvesting seasons (2002 and 2003) the efficiency of different asparagus harvesting aids was investigated from the ATB in Potsdam, Germany. The complexity of production parameters (yield, soil, breed, etc.) in combination with varying local opinions about the optimal operation breakdown for the manual harvesting process aggravated the final evaluation. A collateral motion analysis of the seated harvest is described later.

CALISTO (1999) found a great prevalence of muscular-skeletal disorders for fruit growers based on personal reports, which were backed up by job and posture analysis in general as well as individual measurements of the heart rate and EMG recordings.

STUDMAN (1998) investigated the impact of apple-sorting-table designs on the operators' performance and comfort. His study represents an ergonomic approach to increase productivity and comfort, based on the observation of movements and questionnaires.

Applicable tools for process organization within the horticultural production are REFA time studies (i.e. STOCKEY 1979) or MTM in combination with ergonomic design to minimize discomfort and strain.

Although the evidence of ergonomic improvements was proven in several studies, an impact on horticultural work place design is hardly visible. The low wages paid and the low agricultural value added are named to be the reasons for poor work place design. The problem is increased by dealing with seasonal workers and in consequence the dislocation of costs for medical treatments due to occupational diseases beyond the borders.

On the way to sustainable production systems the economic and ergonomic work place design has to become a basic requirement demanding a broad spectrum of objective, updated and statistically backed up data. The solely monetary evaluation of work place design has to be enlarged incorporating health issues to create sustainable work systems for all of its elements.

Method

Motion analysis system

A custom-made (THOMAS 1997; JAKOB 2004) online motografic system is used to record the human motions (Extrac, Wente/Thiedig, Braunschweig, Germany). Two CCD-cameras locate the spatial positions of light pulses sent from active infrared light diodes attached to the subject. The LEDs are pulsed by the system consecutively to be able to match the tagged positions on the subject's body with the calculated spatial positions of the light pulses. The system emits a total of 50 pulses per second. From the information of both cameras the computer calculates the 3-D-coordinates for each position and presents it online on a computer screen. The calculated values of the positions are also saved on the hard disc. A maximum of eight markers can be used in parallel (Fig. 1).

In addition to the CCD-cameras, the system comprises a video camera. This allows a consistent documentation of the recorded motions and offers the chance to reconstruct irregular movements at any time after the measurements.

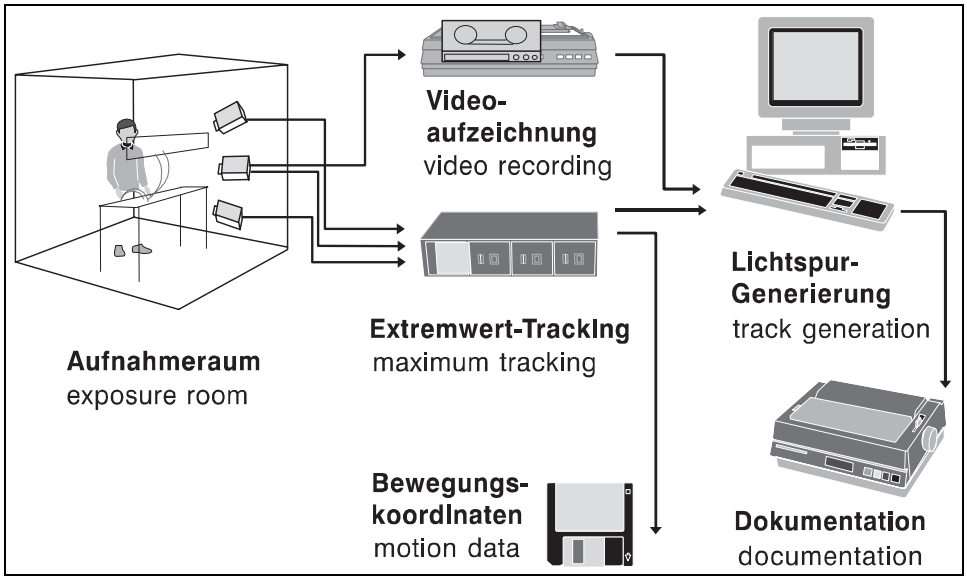


Fig. 1. Set up of the 3-D-motion analysis system manufactured by Wente/Thiedig (THOMAS 1997).

Definition of indicators for the interpretation of human motions

The main goal of the research project was to develop a nouveau software customized for work-scientific needs to interpret the recorded motion data. The design of the software was focused on solving current problems within modern horticultural production allowing the calculation of objective parameters based on the 3-D-coordinates rendering the motions.

In an alternating process, indicators were defined and applied in practical experiments, finally creating a broad spectrum of functions (Jakob 2004).

The newly defined parameters for comparison can be divided into two groups, namely quantitative and qualitative parameters (Jakob et al. 2004). The duration, the speed of motion, the sum of motion or the angles describing work postures are quantitative parameters to objectively compare the motions. Furthermore, there are gained more qualitative parameters from several graphical functions within the new software that facilitate the understanding of the motion data and allow a clear presentation of the experimental results. A 3-D image of the motion track, the area of activity or the angular dimensions in a grey scales-scheme representing the frequency of occurrence are examples for the second group.

The software also allows to interpolate missing data. The volume of interpolation is a major quality parameter for the meaningful interpretation of the results. Two different approaches were realized for the calculation of the missing data: The direct connection of the last and the first visible point of the interrupted motion track, called straight approximation, and the speed-based approximation, which takes into account that the human motion is not straight. For the speed-based interpolation the actual speed and the direction of movement of the last point visible are taken to calculate the most likely motion curve, connecting the last and the first visible point of the interrupted motion track. The longer the interruption of the track and the faster the speed of motion, the stronger is the influence of the applied interpolation algorithm.

Results and Discussion

Several experiments were carried out to prove the suitability of the defined parameters for comparison and to show the increase of information for the evaluation of horticultural work systems.

In Experiment 1, design parameters of a workstation for placing products on a conveyor belt are varied and checked up on their influence on the operating efficiency.

In Experiment 2, different seat constructions on asparagus harvesting aids are reviewed for their ergonomic and functional design.

Experiment 1

The gap between human and machine capacity for the processing of horticultural goods continuously increases, emphasizing the necessity of an appropriate workplace design and the reduction of time-consuming design parameters. An optimal design of man-machine interfaces should enable the workers to increase their overall movement efficiency, characterized by the distance moved and the duration. It should also follow the approved ergonomic guidelines.

A laboratory workplace and homogenous material (wooden sticks, with a mean length of 42 cm, a mean diameter of 23 mm and a mean weight of 110 g) are used to simulate a simple and highly repetitive process of placing products on a moving conveyor belt. Similar processes are often found in horticultural post harvest production lines.

The work task can be subdivided into different motion elements: Reaching, grasping a bundle of material, bringing it to and positioning it one by one on the conveyor belt. A variation in the speeds of the material transport is selected for the presentation of possible information gained by the 3-D motion analysis. The slow machine capacity allows transporting 4500 pieces per hour and at high speed 7300 pieces per hour are transported. Automatic sorting units process up to 50.000 pieces per hour.

The height of the work surface is adjusted at 95/90 cm (top/bottom of compartment), suiting the elbow height of the 50th percentile suggested for light work. The distance between the material and the conveyor belt is kept as short as possible. The storage box for material supply is positioned with a lateral inclination to easier transcend the edge of the box while emptying it. An optimised material supply increases the human capacity.

The experiments were carried out with three healthy subjects, two females and one male, aged between 25 and 30 and a measured body height within the 50th percentile.

Results

The average number of pieces placed on the conveyor belt that was achieved by all subjects within the experiments, was 4000 pieces per hour. The interpersonal variation was very high, ranging between 3000 and 5500 pieces per hour. The highest but also the lowest capacities were achieved at the highest speed of material transport (Fig. 2). The minimum and the maximum values in Fig. 2 are based on the average for sets of experiments. A set of experiments equals the recording of ten separate repetitions of emptying one box with a content of 91 wooden sticks.

To explain the wide variation in the human capacities, the motion data was analyzed in detail. Looking at the overall motion volume for the left and right hand, the lowest and the highest human capacities (Fig. 2, A–D) show significant differences (Fig. 3).

The maximum values (B and D) for both machine speeds were achieved by the same person. The amount of motion for the left and the right hand was nearly equivalent. The faster movement of the conveyor belt (7300 pieces hour^{-1}, D) caused an increase of the mean speed of motion for both hands by 0.07 m s^{-1}.

The human capacities A and C refer to different subjects. However, the work technique is similar, showing characteristic differences in the sum of motion for the left and the right hand and significantly higher values for the overall sum of both hands.

Further interpretation of the motion data showed that an increased speed of material transport can cause a shift in the area of activity, resulting in an advanced distance between the material and the conveyor belt. The upper arm elevation and the opening of the arm increased at

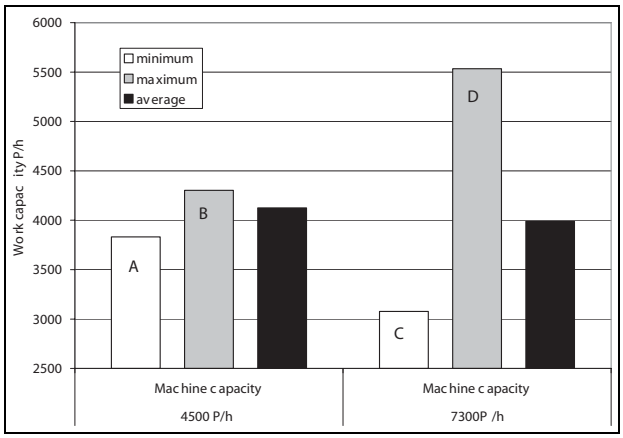


Fig. 2. Variation of the work capacity for all subjects depending on the machine capacity; A to D refer to the sums of motion in Fig. 3.

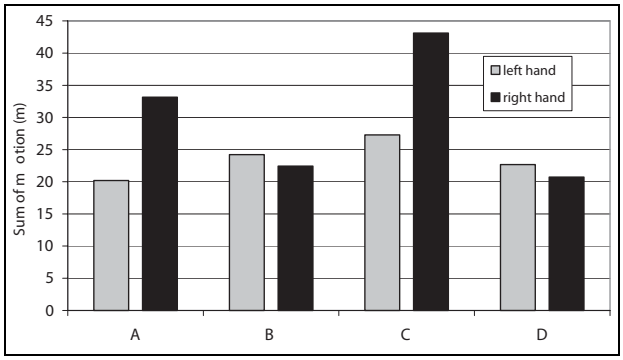


Fig. 3. Sum of motion for emptying one box referring to the minimum and maximum human capacities (A to D) shown in Fig. 2.

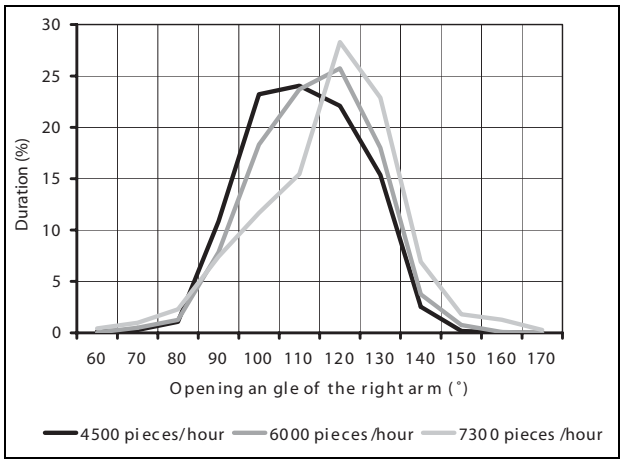


Fig. 4. Angles describing the opening of the right arm for different machine capacities while placing the material on the conveyor belt.

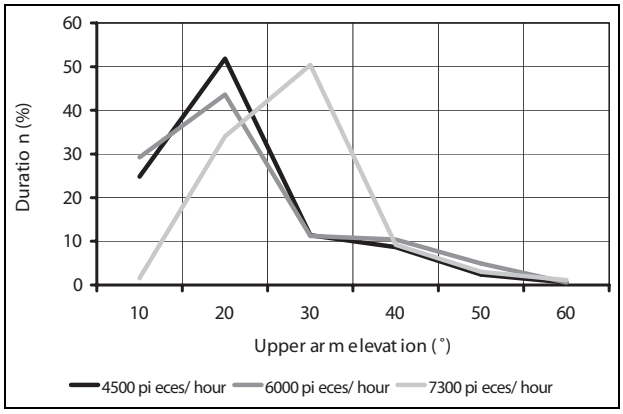


Fig. 5. Upper arm elevation of the right arm for different machine capacities while placing the material on the conveyor belt.

higher machine capacities. This observation is demonstrated in Fig. 4 and 5. However, only one subject was affected by this. The increase of both angles also displays the complexity of human motions. A combined visualization of both angles in one diagram allows a judgment of the motion congruence for one person as well as a comparison of interpersonal variation.

Although the process was short and simple, the interpersonal and personal variations were high. The comparison of the motion data helped to explain this variation and, in consequence, can help to optimise the work technique. The machine capacity was expectedly proven to be a motivating factor speeding up the motions of one subject (Fig. 3, D). A perturbing factor of a high machine speed was also proven, looking at the high variation between subjects and the shift of the area of activity.

Within the scope of production the adjustment of the capacity is up to the plant manager, whose decisions are normally based on experience. There exist no guidelines for this. An optimal synchronization of man and machine capacity is essential to avoid stress and other negative factors influencing the efficiency. Furthermore, it is necessary to achieve a constant and optimal output lasting a whole shift.

The results also prove that the study of complex motions and work situations is not described accurately enough by the duration of a process. An explanation of the variation is not possible if there only exists this single parameter for comparison. The interpretation of additional data describing the process, for example the change of the arm elevation, brings up new results. Risk factors can be revealed and quantified for a more efficient design and training on the job.

Experiment 2

Experiment 2 proves the feasibility of an ergonomic evaluation of workplaces by motion analysis. It implied the comparison of two seats on asparagus harvesting aids. These seats were designed to improve the work situation for harvesting white asparagus spears near ground level. Ordinary guidelines for seating facilities at work cannot be applied because the object of interest is, compared to a normal table stool workplace, in an awkward position. The worker needs to move down and forward to be able to reach the asparagus. Seat 1 is characterized by knee pads to lean on and seat 2 has an upper body rest to lean

against, both to prevent the worker from falling off the seat and from building up unhealthy muscular tension to remain seated (JAKOB et al. 2003).

The harvesting process was standardized and simulated in a laboratory. For this, a tub filled with rye grain was divided into nine compartments and a plastic stick was used to re-enact the harvest of asparagus. The harvesting process was repeated 50 times. Each process started with the nomination of a compartment and ended in an upright sitting position of the subject waiting for the next order. The sequence of nomination changed between two predefined schedules, characterized by a 50 % probability in the middle region of the tub and 25 % in the near and far region. This aims to represent a normal variation of growth in an asparagus plantation, causing a variation in the travel distance towards the spears to be harvested.

For a postural evaluation of the two seats the markers were attached on one side of the body at a time. Six markers were fixed on knee, hip, shoulder, elbow, hand and head.

Results

A questioning of the subjects on their preference of one of the seats can be backed up by analysing the course of motion. The positions of the markers on shoulder, hip and knee were used to calculate the trunk angle. The course of the trunk angle showed significant differences for the construction with the upper body rest (Fig. 6, solid lines). The different curve progressions were caused by the variation of the locations for the simulated harvesting process, permitting the assumption that the seat construction is obstructing the subjects in their motion. To comfortably reach the compartments on the left or the right side of the box, the subjects needed to lean forward enwinding the upper body support.

The course of the trunk angle for the construction with the knee pads was congruent in terms of the wave shape (Fig. 6, broken lines). There were only slight differences in the absolute values of the trunk angles, possibly also caused by the varying locations of the spears. The characteristic breakdown of the work process could be easily identified, which was interpreted as a positive congruence of motion.

Apart from the course of motion, the back posture was evaluated by measuring the spinal flexion, as defined by the distance between hip and shoulder. All values below the normal upright sitting position (reference value) indicated a bent back. The incidence for a bent back was significantly higher for the seat with the upper body rest (Fig. 7). Again, there were strong interpersonal differences. For both seats subject N showed significantly lower values than subject K. Apart from the design of the seat there seems to be a necessity for self-discipline to sit in a healthy and upright position.

Ordinary guidelines for sitting facilities at work cannot be applied for the seats on the asparagus harvesting aids, especially due to the demanded work task. The subject questioning on the preference was backed up by the results of the 3-D motion analysis. Objective criteria like the congruence of motion and the appraisal of the spinal flexion allowed to favour the knee pad seat. An ergonomic evaluation was therefore possible and coherent, customized for the specific needs and not subject to fixed scales. The applied parameters for the comparison of the motions were able to meet the requirements on an objective evaluation.

For the evaluation of the seats different methods (VERGARA and PAGE 2002) could have been used to verify the suitability of the two constructions. Anthropometric guidelines are useful for the definition of functional dimensions of chairs, they do not help to rate a functionality that exceeds the common use, in this case the process of harvesting asparagus. A subjective assessment was applied to measure the comfort, but this only provided restricted and subjective information. The stated measures of comparison supplied important data to rate the lumbar curvature and the course of the trunk angle. An objective evaluation based on several parameters was possible.

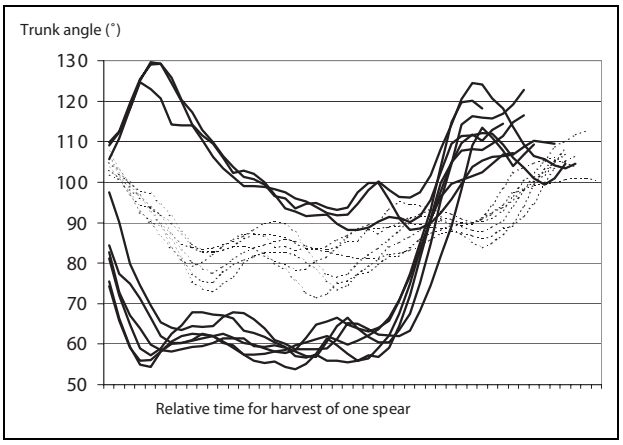


Fig. 6. Course of the trunk angle on the seat with the upper body rest (solid lines) and the knee pad seat (broken lines) for harvesting one spear.

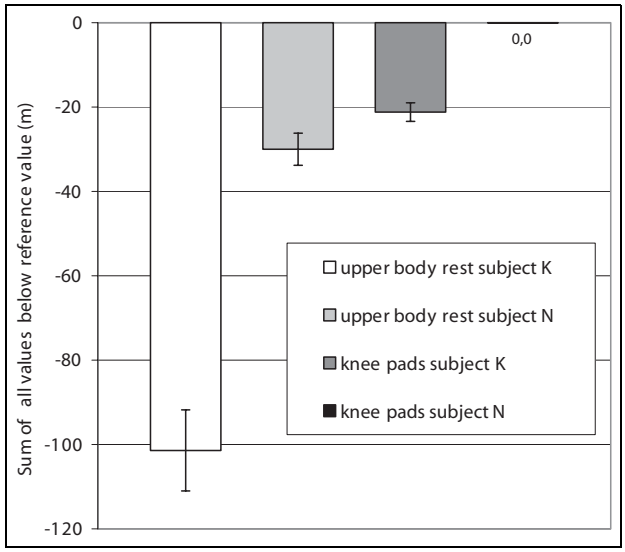


Fig. 7. Comparison of the seats and two subjects (K and N) concerning the spinal flexion.

Conclusions

The selection of two different horticultural issues demonstrated the broad range of possible applications for a motion analysis system in horticulture. Ergonomic risk factors were revealed, but the use for individual training on the job as well as for process control is also possible, covering economic and ergonomic aspects.

Compared to existing work-scientific methods like predetermined time studies (MTM, work factor), REFA time studies or CAD applications like SAMMIE, RAMSIS or Mannequin (MATTILA and KARWOWSKI 1992), the motion analysis considers movements, the expenditure of time and body postures at the same time. Additional valuable information is provided to better understand and explain the collected data, and it supports the user in revealing reasons for data variation. The 3-D-coordinates are the basis for a broad spectrum of interpretation. Furthermore, the results are independent from the observer. This is a clear advantage to work-scientific methods that are based on a situation analysis like REFA time studies with compulsory performance rate or the nomination and quantification of relevant body postures by observers (LOWE 2003) for a postural analysis. An exact and objective determination of postures and the exposure dose can be realized with the described system.

Although laboratory settings and simplified work processes were analysed, the variation within performance data was still large. This emphasizes the need for a capacious analysing tool to explain the remaining variation caused by internal and external factors. The more of information gained from one experiment facilitates the comprehensive analysis of work processes on the basis of statistically validated data. The range of data underlying the same internal and external influence factors reduces the impact of variation in the results. Economic and ergonomic design parameters can be considered, also based on the same set of data.

References

BARRETT, A.L. and F.A. FATHALLAH 2001: Evaluation of four weight transfer devices for reducing loads on the lower back during agricultural stoop labor. In: Proceedings of ASAE, St. Joseph, Mich., Paper Number **01-8056**, 1–9.

BAUA 2001: Volkswirtschaftliche Kosten durch Arbeitsunfähigkeit 2001. http://www.baua.de/info/statistik.

CALISTO, C. 1999: Ergonomic investigations in fruit growing. Dissertation Universität Hohenheim, Verlag Grauer, Stuttgart.

ICFTU 2003: International Confederation Of Free Trade Unions, Trade Union World, Briefing, No. **7**.

JAKOB, M., M. GEYER and W. BOKELMANN 2003: 3-D-motion analysis as a tool for objective ergonomic evaluation of dynamic horticultural work processes. Proc. XVth Triennial Congress of the International Ergonomics Association, Seoul, Korea.

JAKOB, M. 2004: Bewertung von Arbeitsprozessen im Gartenbau mit Hilfe der dreidimensionalen Bewegungsanalyse, Dissertation, Humboldt-Universität Berlin.

JAKOB, M., M. GEYER and V. IVANOV 2004: Gestaltung von Mensch-Maschine-Systemen im gartenbaulichen Nachernteprozess auf der Basis bewegungsanalytischer Untersuchungen, Z. Arbeitswissensch. **58** (1), 53–60.

KAHRU, O., P. KANSI and I. KUORIUKA 1977: Correcting working postures in industry: A practical method for analysis. Appl. Ergon. **8 (**4), 31–38.

LOWE, B.D. 2003: Validity of observational posture analysis methods for the wrist and forearm, Proc. XVth Triennnial Congress of the International Ergonomics Association, Seoul, Korea.

MATTILA, M. and W. KARWOWSKI 1992: Computer applications in Ergonomics, Occupational Safety and Health, North Holland.

MATTILA, T., E. MUUTTOMAA and M. PELTONEN 2001: The development of strawberry picking methods. In: NYGÅRD, C.-H. (ed.): Proc. NES. Promotion of health through ergonomic working and living conditions: Outcomes and methods of research and practise: publications **7**, 464–466.

MEYER, R. 2004: Research an recent ergonomic development in prone posture workstations for agriculture, Proc. ASAE meeting 2004.

MESSERSCHMIDT, U. 1993: Ergonomische Analysen bei Pflanzmaschinen, Diplomarbeit TU München, Institut für Landtechnik Freising-Weihenstephan.

MOHR, D. 1998: Evaluation of physical hazards at workplaces in agriculture. Landesinstitut für Arbeitsschutz und Arbeitsmedizin Potsdam, http://bb.osha.de/publications/vortraege/lublpap1/paper1.htm.

OSHA 2004: Success stories; http://www.osha.gov/SLTC/ergonomics/success_stories.html.

REFA 1992: Methodenlehre des Arbeitsstudiums, Teil 2: Datenermittlung. Carl Hanser Verlag, München.

STOCKEY, F. 1979: Arbeitsplanung und Arbeitsgestaltung im Produktionsgartenbau. Betriebs- und Marktwirtschaft im Gartenbau, Heft **7**, Berlin, Hamburg: Verlag Paul Parey.

RULLMANN, M. and S. KLEISINGER 2003: Ergonomic investigations in the prone working posture during pickling cucumber harvesting. Proc. XXX CIOSTA-CIGR V Congress, Turin, 1008–1016.

STUDMAN, C. 1998: Ergonomics in apple sorting: A pilot study. J. Agric. Eng. Res. **70**, 323–334.

THOMAS, J. 1997: Anwendung einer neuen Online-Lichtspurtechnik in Kombination mit Videotechnik zur Bewegungsanalyse. Bornimer Agrartechn. Berichte, Heft **16**, 82–91.

VERGARA, M. and A. PAGE 2002: Relationship between comfort and back posture and mobility in sitting-posture, Appl. Ergon. **33**, 1–8.

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