# Ergonomic evaluation of hand-hoes for hillside weeding and soil preparation in Honduras

**Brian G. Sims[1], David H. O'Neill[1], Robert J. Walle[2], Jim Ellis-Jones[1], Alejandro Rivera Rosero[3] and Jofiel Jirón Estrada[3]**

**Abstract.** Ergonomics parameters (heart-rate and total heart-beats per unit of work) were applied to the evaluation of five hoes for weeding small-farm plots on hill-slopes. The same measurements were employed to compare the effort involved in different hand-powered soil tillage systems (conventional, minimum and zero). Results show that the physiological cost of hoeing increases with slope angle, but the hoe designs evaluated did not differ sufficiently to show differences in the effort required to use them. Reducing tillage to strip or zero till reduces the physiological demand and increases labour productivity (at the cost of applying herbicide). However, economic analysis indicates that the differences are unlikely to result in adoption in farming systems where family labour is the dominant source of power.

**Key words:** Economic evaluation, manual hoeing, reduced tillage.

**Resumen.** Se aplicaron los parámetros ergonométricos (frecuencia cardíaca y número total de latidos por unidad de trabajo) a la evaluación de cinco azadones para deshierbar parcelas pequeñas en laderas empinadas. Se emplearon las mismas mediciones para comparar el esfuerzo involucrado en tres sistemas manuales de labranza del suelo (tradicional, mínima y cero). Los resultados indican que el costo fisiológico de azadonear aumenta con la inclinación de la ladera, pero los diseños de azadones empleados no difirieron suficientemente para mostrar diferencias en el esfuerzo requerido para usarlos. Al reducir la labranza a mínima o cero, se reduce la demanda fisiológica y se incrementa la productividad de la mano de obra (al costo de aplicar herbicida). Sin embargo, el análisis económico indica que las diferencias probablemente no resulten en adopción en sistemas de producción donde la mano de obra familiar es la fuente de potencia dominante.

**Palabras claves:** Azadones, ergonomía, evaluación económica, labranza reducida, laderas.

## INTRODUCTION

Human power is of major importance in developing country agriculture. FAO statistics indicate that 71% of the energy invested in the agriculture of developing countries comes from humans, 23% from work animals and only 6% from engine sources (FAO, 1987). Hand-hoes are arguably the most important tools employed worldwide for soil tillage and weeding operations and the number of operators relying on them is in the billions.

Given their importance, the ergonomically efficient design of hand-hoes has the potential to ease the effort required for their use and to enhance operator comfort. A special case is the use of hoes in hillside agriculture where steep slopes may demand postures which are awkward for the operator and more tiring to sustain for long periods. There may well be a need for a range of designs for use on steep hillsides or for different tillage operations and the objectives of the study were to:

i) Introduce the concept of ergonomics in equipment design, research and development with a focus on the needs of marginal, resource poor, subsistence farmers.
ii) Apply ergonomics principles to investigate design parameters for hoes used for hill-side weeding.
iii) Assess the effort needed for different soil preparation practices with hoes, and the effect of the tillage systems on maize yield, quality and profitability.

[1] Agricultural Engineer, Ergonomist and Agricultural Economist, respectively, Silsoe Research Institute, Wrest Park, Silsoe,Bedford MK45 4HS, UK.

[2] Soil Conservationist, Soils of Tomorrow, P.O. Box 14741, Gainesville, Florida 32604, USA.

[3] Ingenieros Agrónomos, Escuela Agrícola Panamericana, Zamorano, P.O. Box 93, Tegucigalpa, Honduras.



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## MATERIALS AND METHODS

The work was undertaken at the Panamerican Agricultural School (Escuela Agrícola Panamericana - EAP, Zamorano, Honduras) during the 1996 cropping cycle and was a collaborative project between EAP and Silsoe Research Institute, UK (Rivera Rosero, 1996).

**Heart-rate monitor.** A proprietary heart-rate monitor (BHL-6000 manufactured by Baumann-Haldi SA, Switzerland) was used to monitor heart-rate in terms of beats per minute and total number of beats (Smith *et al.*, 1994). The monitor detects electrical activity of the heart via a sensor strapped to the subject's chest. After recording during the work period, data are transferred to a computer and interpreted by means of specialized soft-ware. Results displayed include heart-rate and total number of heart-beats.

**Hoes.** The examination of the effects of hoe design and slope on effort compared performance using five hoes whose characteristics are summarised in Table 1. All have wooden handles 1.11 m in length and a diameter in the range of 34 - 45 mm and carbon-steel blades (Figure 1).

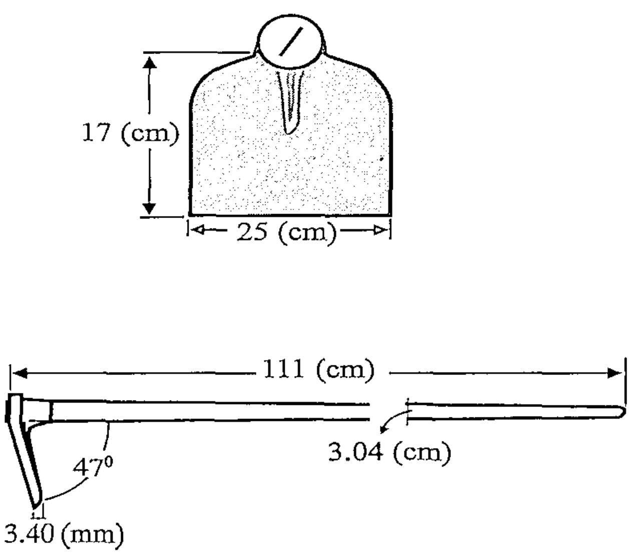


**Figure 1.** Specifications of the hoe designs used for weed control on hillsides.

**Table 1.** Specifications of the hoes used for weed control on hillsides

| Hoe | Width mm | Length mm | Thickness mm | Angle[1] |
|---|---|---|---|---|
| 1 | 250 | 170 | 3.4 | 67 |
| 2 | 200 | 170 | 3.4 | 75 |
| 3 | 200 | 170 | 3.4 | 67 |
| 4 | 250 | 170 | 3.4 | 75 |
| 5 | 212 | 185 | 2.9 | 80 |

[1] angle between shaft and blade (degrees)

Hoe #5 is the design locally available in the market, hoes #1-4 were fabricated in the EAP workshop for the purposes of this evaluation. The dimensions of hoes in use by farmers is infinitely variable as they are modified to suit individual users and specific working conditions. Dimensions of the blades will vary with use. The weight of the hoes will depend on the dimensions of the handle, the type of wood used and the wear of the hoe; the weights of the hoes used in this study ranged from 1.36 - 2.28 kg.

The tools used in the tillage trial were a machete, and a farmer-owned hoe, the specifications are given in Table 2. Seeding was with a pointed planting stick with the seeds carried in a metal container tied to the farmer's waist.

**Table 2.** Specifications of the tools used for the soil tillage trials

| Tool. | Length Total m | Length Blade mm | Blade width mm | Handle diameter mm | Weight kg |
|---|---|---|---|---|---|
| Machete | 0.75 | 625 | 50 | 40 | 0.52 |
| Hoe | 1.25 | 161 | 255 | 34-45 | 2.25 |

**Operators.** Four operators (all male) were used during the two trials, their physical characteristics are shown in Table 3.

Table 3. Physical characteristics of the operators

| Operator and operation | Age (years) | Height (m) | Weight (kg) |
|---|---|---|---|
| **Hillside weeding** | | | |
| Operator 1 | 17 | 1.6 | 64.1 |
| Operator 2 | .20 | 1.7 | 70.0 |
| **Tillage** | | | |
| Operator 3 | 17 | 1.6 | 64.1 |
| Operator 4 | 24 | 1.8 | 73.6 |

**Location and season.** The hillside weeding trial was undertaken in two sites:

i) Land at EAP (32 km SE of Tegucigalpa the capital of Honduras) at an altitude of 800 masl, annual rainfall 1105 mm and mean temperature 24° C.

ii) A small-farmer plot at Lavanderos, El Paraíso Department at an altitude of 1350 masl, annual rainfall of 1200 mm and a temperature range of 12-18° C.

The locations were divided into three slope categories: 0-5°, 15-20° and 25-30°. Weeding was also conducted in two distinct phases of crop production (criollo maize): before sowing (April 1996) and 30 days after sowing (July). Soil texture is sandy clay loam in the two sites and were largely free of stones on the surface.

The land preparation tillage trials were conducted on the EAP site immediately prior to maize sowing in June 1996.

**Weeding trials.** Each operator worked for 25 minute periods with each of the five hoes on the three categories of slope, three replicates were worked in each case. A rest period of 30 minutes was allowed between each working session. In each case, the area worked, the mean heart-rate and the total number of beats were recorded.

In order to estimate the total area required for the trial, test runs were conducted with the operators to measure their output in terms of area hoed in 20 minutes (from a total work time of 25 minutes). The dimensions of the plots measured 8 m x 7 m (56 $m^2$) in location one; 7 m x 5 m (35 $m^2$) in location two. The 30 plots in each location were delimited with stakes and string.

During the actual trials the operators were alternated so that one was working while the other rested and only three plots were completed per day by *each operator* to avoid excessive fatigue. The operators were allowed free access to fresh water but did not eat, smoke or drink anything else during the trial period. The total time spent in each location was five days.

The experimental design was a 5 x 3 factorial and the results were analyzed with SAS soft-ware.

In the second phase of the experiment the marked plots were not strictly adhered to, rather the rows of maize were hoed in the conventional way for 25 minutes in each of the treatments and replicates and data for 20 minutes were recorded.

**Tillage trials.** The four tillage treatment trials were laid out in a randomized complete block design. There were three replicates for the ergonomics treatments and four for the yield measurements. The trial plots measure 5 m x 6 m and were delineated with stakes and string. All plots were cleared by machete prior to the tillage treatments which comprised:

i) Conventional hoeing of the entire area to a depth of 15 cm.

ii) Minimum, or reduced, tillage where Glyphosate herbicide was applied at 2.0 L/ha (820 g a.i. $ha^{-1}$) and strips 20-30 cm wide spaced at 80 cm were hoed to a depth of 15 cm.

iii) Zero tillage with direct seeding following application of Glyphosate at 2.0 L/ ha.

iv) Zero tillage with Paraquat at two litres per hectare (480 g a.i. $ha^{-1}$).

Measurements were taken of resting and working heart-rates, total number of heart-beats and the time taken to work each plot. Yield data were taken from a 3 m wide strip in the centre of each plot.

**Economic analysis.** To enable a partial budget analysis of the tillage options, data were recorded on the amounts and value of the inputs that differed between treatments (labour and herbicide), as well as yield of maize and their farm-gate value. The analysis examines the additional costs and benefits attributable to changes in farming practice and so estimates the economic advantage of a possible change.

## RESULTS AND DISCUSSION

**Hill-side weeding.** Analysis of variance indicates low variability for heart-rate (CV = 6.20%) and total beats (CV = 6.34%) but a higher value (CV = 35.8%) for the area worked. This could be due to the number of other factors affecting the area covered whilst the operators maintained a comfortable work output. Factors affecting the output are soil moisture, soil compaction, and ambient conditions (temperature and relative humidity). Table 4 compares the treatment means.

**Table 4.** Separation of means for heart-rate, total number of beats and area worked

| Treatment | Heart-rate per minute | Total beats in 20 minutes | Area worked, $m^2$/20 minutes |
|---|---|---|---|
| Before sowing | 123 a | 3076 a | 47 a |
| After sowing | 119 a | 2934 b | 33 a |
| Mean | 121 | 3005 | 40 |
| Slope 0-5° | 121 b | 2989 b | 49 a |
| Slope15-20° | 117 c | 2918 b | 44 b |
| Slope 25-30° | 125 a | 3119 a | 27 c |
| Mean | 121 | 3009 | 40 |
| Hoe 1 | 119 a | 2952 a | 41 a |
| Hoe 2 | 121 a | 3049 a | 37 a |
| Hoe 3 | 122 a | 3022 a | 41 a |
| Hoe 4 | 121 a | 3022 a | 39 a |
| Hoe 5 | 120 a | 2996 a | 39 a |
| Mean | 121 | 3008 | 39 |

Means with the same letter in each column do not differ significantly (P = 0.05).

The heart-rates produced by the work varied from 86 to 150 beats per minute which falls into the category of moderately heavy work (Nag and Pradhan, 1980). Table 4 shows little difference between the means for physiological output or area covered, this is due to the sustained hoeing rate of 59-61 strikes per minute maintained throughout the experiment (and considered optimum by Nag and Pradhan *op cit*).

In the case of differing slopes it is clear that the 25-30° range requires greater effort (125 beats per minute compared with the other ranges: 117 and 121 beats per minute) it could be that the posture of the operator plays a part in this as greater effort is required to maintain equilibrium. The area worked is significantly greater on the plots with least slope and this could be due to the effort and time needed to adjust posture when working on greater slopes.

When the results for the individual operators are compared it can be seen that there are no significant differences between the hoes in either physiological work-load or area hoed. Figure 2 gives an example of the mean heart-rates for both operators in the second crop phase using the five hoe designs. Figure 2 shows that slope only had a significant effect on operator 1, the fitter of the two as deduced from his lower heart-rates overall.

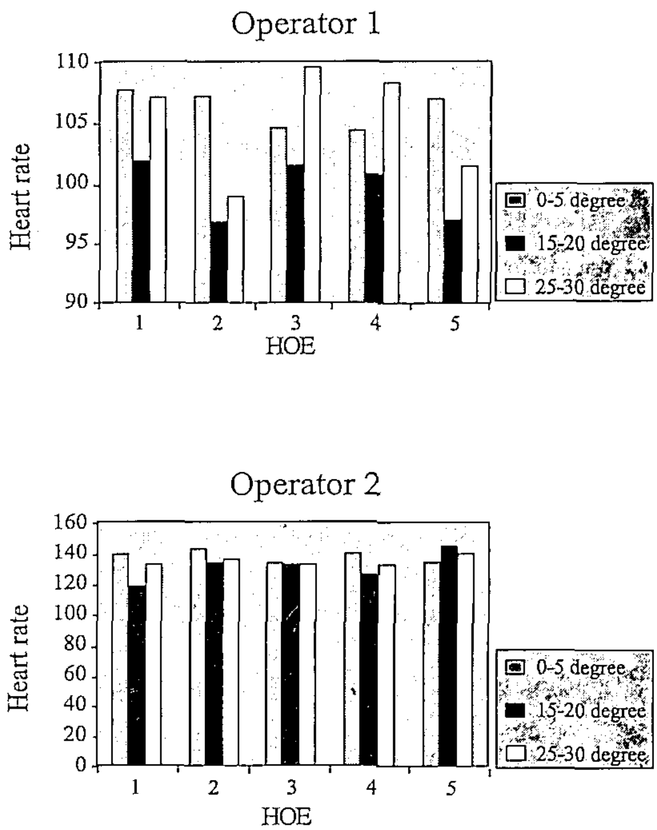


**Figure 2.** Mean heart-rates (during 20 minutes) for one operator on three slopes ($0\text{-}5^0$, $15\text{-}20^0$ and $25\text{-}30^0$) with five hoes.

Slope, however, has a significant effect on heart-rate and area hoed. Before sowing the greatest productivity was achieved on the 15-20° slope, however after sowing the productivity was greatest on the 0-5° slope (Figure 3). The probable reasons for this difference are variation in weed density and maturity, soil conditions (especially moisture) and ambient conditions.

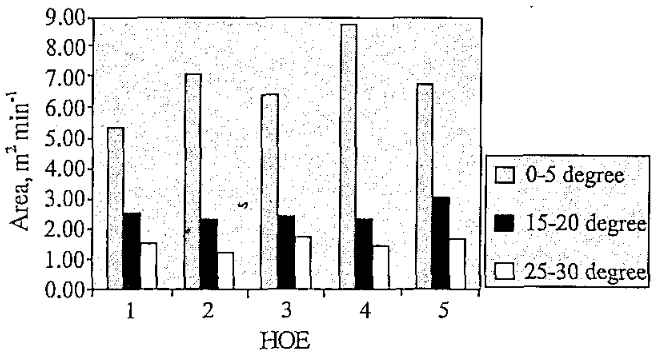


**Figure 3.** Area weeded with the five hoes on three slope ranges (0-5$^0$, 15-20$^0$ and 25-30$^0$).

Greater differences in the performance of the hoes may have been anticipated if there had been greater variation in their design parameters. For example they all had the same length of 1.11 m and Nwuba and Kaul (1986) concluded that a 20% reduction in spinal force can be achieved when using hoes with longer handles.

**Tillage.** The data for comparing operator performance with different soil tillage treatments are summarized in Tables 5 and 6. The speed of work (strokes per minute) was recorded throughout the trial. Weed clearing by machete was common to all treatments and the mean speed was 39 strokes per minute with a range of 38 to 41. For hoeing, the mean figure was 41 strokes per minute with a range of 34 to 43. The time taken for weed clearing by machete was 7.25 $m^2$ per minute equivalent to 22 hours per hectare, with a range of 15 to 39 hours per hectare.

**Table 5.** Work output, heart-rate and total heart beats for tillage systems

| Tillage | Area tilled, $m^2$/min (days/ha) | Heart-rate/ min | Total heart beats/ 30 $m^2$ |
|---|---|---|---|
| Conventional | 0.97 (21) | 131 | 3908 |
| Minimum (reduced) | 1.56 (13) | 120 | 3553 |
| Treatment standard error of deviation | 0.105** | 5.97 | 118.3* |

Treatments significantly different at * = P = 0.05; ** = P =0.001

**Table 6.** Work output, heart-rate and total heart beats for maize planting systems

| Tillage | Area planted $m^2$/min (days/ha) | Heart-rate/ min | Total heart beats/ 30 $m^2$ |
|---|---|---|---|
| Conventional and minimum | 3.93 (5) | 90 | 2573 |
| Zero | 2.97 (7) | 93 | 2501 |
| Treatment standard error of deviation | 0.369[1] | 2.36 | 171.1 |

[1] Treatment significantly different at P = 0.06

The area tilled is very significantly less with minimum or strip tillage compared with conventional tillage of the whole area (Tables 5 and 6). As the work is of a similar nature, the heart-beats are not significantly different, but the total heart-beats to till the 30 $m^2$ plots reflect the increased work load with conventional tillage which is significantly greater than minimum tillage.

The planting performances in Table 6 do not show any significant differences (P = 0.05) between the treatments. However the area planted is close to being greater (P = 0.06) with conventional and minimum tillage which is to be expected as the tilled soil offers less resistance to the planting stick and hence requires less effort from the operator.

Yield data for the tillage trial are given in Table 7. For this part of the experiment the zero tillage treatments included both Paraquat and Glyphosate, and there were four replicates.

**Table 7.** Yields of healthy maize from four tillage treatments

| Tillage | Mean maize yield, kg $ha^{-1}$ |
|---|---|
| Conventional | 994 |
| Minimum | 708 |
| Zero with Paraquat | 1097 |
| Zero with Glyphosate | 786 |
| Treatment standard error of deviation | 292.3 |

There was no significant difference between maize yields.

**Economic analysis of tillage systems.** A partial budget analysis was used to compare zero, minimum or reduced (strip) and conventional tillage. This has been based on average yields achieved between treatments, labour savings resulting from the use of either Paraquat or Glyphosate for weed control rather than tillage in land preparation, the cost of the herbicides and the additional labour required for their application and maize planting. The results are shown in Table 8.

This indicates that with zero tillage (using Paraquat) a yield increase of 103 kg $ha^{-1}$ can be achieved over conventional tillage together with a saving of 18 person-days $ha^{-1}$ through a cash investment of $US12 for herbicide purchase. At a hired labour cost of $US1.54 per day (the daily agricultural wage in Honduras in 1996), productivity increases by $US36 $ha^{-1}$ for zero tillage using Paraquat. The other options, using Glyphosate, give lower productivity than conventional tillage. However, as the price of labour increases, the reduced tillage options would become increasingly attractive.

Where family labour is used and there are no competing demands on that labour, it is likely that the household would be satisfied with the productivity achieved with conventional tillage given the reduced risk and cash outlay required. If oxen are used for ploughing, as occurs in many cases, the cost of land preparation will be considerably less making conventional tillage a more attractive option.

**Table 8.** Partial budget analysis of zero, minimum (reduced or strip) and conventional tillage. Price used for corn was $ 0.21/kg and labour $ 1.54/day

| | BENEFITS | | | | | COSTS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Increased benefits | | Reduced tillage costs | | | Increased costs | | Additional labour | | | | |
| Tillage/ Herbicide | Yield increase/ decrease kg/ha | Value $ | Decrease in labour days/ha | Value $ | Total benefits/ ha | Herbicide L/ha | Value $ | Planting and spraying days | Value $ | Total costs | Net benefits/ ha | Rank |
| Zero/Paraquat | 102 | 21 | 21 | 32 | 53 | 2 | 12 | 3 | 5 | 17 | 36 | 1 |
| Zero/Glyphosate | -209 | -44 | 21 | 32 | -12 | 2 | 22 | 3 | 5 | 27 | -39 | 3 |
| Conventional | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Minimum/ Glyphosate | -286 | -60 | 8 | 12 | -48 | 2 | 22 | 1 | 2 | 24 | -72 | 4 |

## CONCLUSIONS

- The physiological effort required by operators to hoe on hillsides depends on the severity of the slope. Steeper slopes requiring greater effort.
- The hoes evaluated did not have sufficiently different design parameters to result in differences in the human effort required or the area worked.
- Minimum or strip tillage allows a greater work output at less physiological cost to the operator.
- Labour productivity and the human effort involved in planting are not affected by the tillage system adopted.
- Partial budget analysis of human-powered tillage systems indicates that, despite the labour savings and reduced physiological cost, farmers are unlikely to change from their conventional system, until the price of labour increases or its availability decreases.
- Perhaps the most important conclusion is that the application of ergonomics, in conjunction with other disciplines, to small-farmer mechanization problems can give valuable insight into the differences between options and on their adoptability. Ergonomics is a vital element in the search for improved implement design for farmers working in marginal conditions.

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