Agricultural derived tools for ground processing in humanitarian demining operations: set up of testing facility in Jordan

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Abstract— **As often acknowledged, humanitarian demining is mainly a gardening process. Because of its intrinsic threat, it requires extreme care, but the tools and the machines used for demining are very similar to equipment used in agriculture as the aim in the end is always ground processing. Nevertheless, mechanical technologies available on the humanitarian demining market are extremely expensive, the price of the cheapest machine being approximately 120.000 US$. Gardening tools as shovels and shears are used in support of manual demining operations but exceptions exist in which they become the prime demining technologies. This is the case of Sri Lanka and Jordan, where, due to particular environmental characteristics of soft sandy soil and small plastic anti personnel landmines, Norwegian People's Aid (NPA) has implemented the rake system. The method encompasses fully excavation by using simple hand rakes with longed handle. As final stage of the first author's PhD research into Participatory Agricultural Technologies (PAT) for Humanitarian Demining, involving the adaptation of power tillers to demining applications, the test of the module for ground processing tool to be attached to the power tiller - tractor unit will take place in Jordan in March 2008, supported by the Faculty of Agriculture of the University of Jordan and NPA Jordan.**

After introducing briefly the project, the paper describes the design of the ground processing tool to be tested, the set-up of the testing facility in Jordan including the production of the tool supporting frame and the possible use of such facility for testing new tools derived from agricultural technologies targeting different soil and landmine environments.

I. Introduction

There is increasing consensus on the fact that landmines heavily affect the development of contaminated countries and that mine action activities need to be integrated into general development initiatives [1].

There is also general acknowledgment that machines have fallen short of expectations: only few are actually employed in the field and are often down for maintenance waiting for spare parts or experienced technicians able to fix them coming from abroad [2].

These reasons are at the base of the idea of adapting commercially available power tillers to demining applications by developing different modules attachable to the main tractor unit using a participatory design methodology.

In fact we believe that involving deminers into the whole design process would allow them to get familiar with the innovation process, which is a key component of the development process, and would help realizing a machine nearer to real needs, sustainable because made of materials available locally and therefore more efficient.

The project presented here therefore regards the participatory design and development of a new small machine for helping removing landmines in the Vanni region in Sri Lanka and in Jordan, where landmines are of the small plastic type containing not more than 50g of TNT. The whole work encompasses the realization of three modules:

- tractor unit
- ground processing tool
- vegetation cutting tool

and the control unit to drive the machine from the safe distance of 20m, set by local authorities.

The tractor unit is the power tiller, opportunely modified to support other modules, provide sufficient traction and adapted to the remote control [3], while the vegetation cutting module can be attached on the front of the machine when vegetation is too thick for the machine to pass through; it is powered by the powertiller engine and it is supported by the same frame of the ground processing tool [4]. This paper focuses on the ground processing tool that is the means by which landmines are lift up on soil surface to facilitate later hand removal by deminers. The ground processing tool is placed on the front of the machine, to allow landmines to be removed before the tractor unit passes over them.

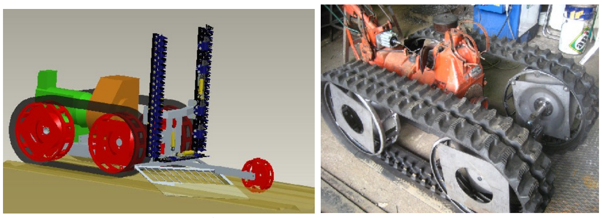

Fig. 1. Digital mock up of robot composed by three modules: tractor unit, vegetation cutting tool and ground processing tool. Picture of tractor unit physical prototype.

II. DEFINITION OF REQUIREMENTS

Before starting the project, a field visit to Norwegian People's Aid (NPA), the NGO partner of the project, in Sri Lanka was organized; we asked deminers to indicate in which operations they would have liked to be helped by a new small machine. Between standard operational procedures currently in use by NPA, they indicated as more boring and difficult the operations of vegetation cutting, specially palm leafs and hard ground processing [5].

In fact, no metal detectors are employed as soil is ferrous and mines have very low metal content; instead, ground is excavated at the depth of 100mm, specified by local authorities, to expose to eye sight buried landmines. Two simple rakes with handler extended to 2m are used: light rakes to remove loose soil and hard rakes to process more compact and deep soil.

Fig. 2. Light and heavy rakes in use in Sri Lanka.

The rake system, currently employed by NPA in Sri Lanka and Jordan, is also known as Rake Excavation and Detection System (REDS) (fig.3). It consists of full excavation, preferably achieved using only the light rake, which no matters how much force is applied on it, due to its numerous and flexible tines, the pressure it exerts on soil is lower than the minimum required to activate landmines (10464Pa, for Type72A, the most sensitive landmine found in the regions). If soil is too hard and light rake becomes ineffective, the heavy rake is used to scarify ground; deminers place the rake head in front of them in the clearing lane and gently pull it back toward them. The two curved rake tines plough back through the soil; their curvature is such that mines are approached on the side and the pressure plate on top is not touched. The raking action is repeated for the entire width (1m) of the clearing lane. When a mine is discovered, it is exposed using either the rakes or other hand tools.

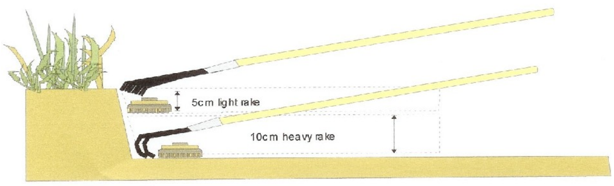

Fig. 3. Light and heavy rakes general use in REDS (Source: Andy Smith).

Work on the ground processing tool module of the machine started after the work on the tractor unit was already at an advanced state. In fact, two working configurations for the ground processing tool are possible, one with the ground processing tool at the back (G-P-B) and one with it at the front (G-P-F). The choice influences tractor unit performance and simplicity. We have identified parameters that contribute to achieve extreme simplicity and effectiveness, referred to as Simpleffectiveness (fig. 4).

SIMPLEFFECTIVENESS

forward/backward motion (traction)
steering: 1m curve radius
energy supply to end-effectors
stability
assessment of ground processing depth
mine disposal
safety of operator
shock wave protection for machine
(and operator, in manual use)

Fig. 4. Simpleffective parameters.

The choice of placing the ground processing tool at the front or at the back is subject to the evaluation of Simpleffective parameters values in the two cases. A matrix reporting "plus" (advantages) and "minus" (drawbacks) related to each parameter for the two configurations has been prepared. Later it was completed by adding other two columns reporting "known effects" and "possible improvements" for both the configurations. Those columns were filled in with the results obtained by tests and simulations on different models, related to each parameter.

After testing the first armoring design we chose to place the ground processing tool at the front. The preferred back position was abandoned as the breakable joint specially designed to fit between powertiller driven wheels and the driving stub axles failed to work as low frequency wave filter. Therefore it did not protect the drive train from unhealthy mechanical vibrations, even if breaking due to the explosion underneath the wheel and allowing the wheel to jump away [6].

Therefore the task of the ground processing tool placed at the front of the machine became to remove landmines before the tractor unit passage and to process the soil at constant depth in order to make demining activities with excavation tools easier for deminers, never pushing mines deeper but possibly lifting them up.

The power tiller we are employing as tractor unit has 7.5kW engine; due its limited capacity, energy consumed by the ground processing module should be as low as possible; other important requirements the tool has to meet are the general ones valid for the whole machine: it should be low-cost, easy to use and maintain, robust, made of few simple parts, easy to find on the local market and able to work in dusty and dirty environment at high temperatures.

III. PRELIMINARY ANALYSES

Because it can be processed with simple rakes, soil can be classified as light or soft both in the Vanni region of Sri Lanka and in the Southern minefields in Jordan at the boarder with Israel, where NPA is using REDS.

Landmines mostly found are small, antipersonnel, plastic, blast mines. Due to their small size and low explosive content, even if accidentally actuated by the action of the hard rake, they don't cause injuries to deminers wearing proper personal protection equipment. As reference for designing the ground processing tool, we considered the landmine smallest in dimension mostly found in the two countries. In Sri Lanka this is Type72A, while in Jordan it is M14. The explosive content of Type72A is 50g of TNT, while the one of M14 is 30g of tetryl.

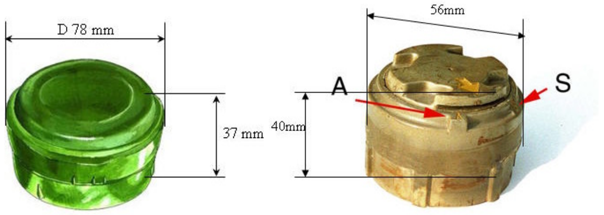

Fig. 5. Type72A and M14 antipersonnel landmines dimensions (Source: Andy Smith).

Other bigger and more dangerous landmines can also be found in both countries, including fragmentation types and anti-tank mines; the machine is anyhow targeting only small plastic landmines, which are also the most common types, as a major requirement for it is to be low cost and therefore with limited power. Before starting clearance it is generally possible to say in which minefields bigger and more dangerous mines can be found: the machine will not be used in those areas.

To achieve the main goal of processing hard soil, as required by deminers, the ground processing tool has to substitute the heavy rake. Therefore, it has to process the soil at required constant depth and expose landmines by lifting them up on soil surface, without actuating them.

The machine can support manual deminers both in area reduction operations and in landmine clearance, depending on the minefield structure and clearance procedures. In fact, where landmines have been laid in well defined patterns along "mine-belts", usually for defending trenches during conflicts, such as in Sri Lanka, the most efficient way to employ the machine would be simply to locate the beginning of the mine-belt; deminers can later proceed to the manual clearance of the belt without wasting time working on clear land. The machine could be employed in support of proper mine clearance operations where landmines are found in random locations. This is the case of Jordan, where even if landmines have been used mainly on borders, therefore have been placed in an ordered, patterned manner, the landslide action due to the rainfall caused them to shift location.

To achieve different aims, different ground processing tools have to be designed. Where landmines are found at random locations, the ground processing tool has to lift mines from the soil and collect them, while where landmines are laid in patterns, like in Sri Lanka, the ground processing tool has to lift them up and leave them there in order to allow manual deminers to locate the mine-belt.

The ground processing tool that has been designed and will be tested in Jordan in March 2008 is of the second type: its task is to process the ground at constant required depth, to lift buried landmines, to remove them from the machine lane and to leave them on top of soil on the side of the lane.

Hopefully, more ground processing tools suitable to different environments will be designed, developed and tested in the framework of a research project between the University of Jordan and the University of Genova in Italy, recently submitted to the Arab Science and Technology Foundation.

IV. GROUND PROCESSING TOOL DESIGN

Primary tillage is defined as the process of loosening the soil from an initial compact state by dragging a metal implement through it. This is exactly what the ground processing tool, made out of steel, to be easy repairable in a local workshop by welding, has to do. Therefore, it is of great interest to look into tillage theory before starting the design of a new tool.

Soil is a special example of granular (solid) material, containing in smaller quantities water (liquid) and air (gas). It is a three phase system extremely weak in tension, very strong in compression and in practice it fails mainly in shear [7]. Failure is defined by the Coulomb criterion in which the maximum shear stress is a function of the compressive stress normal to the plane of shear failure (eq.1).

$$S = C + \sigma \cdot \tan \varphi \qquad (1)$$

Where, S is the soil strength, i.e. the maximum shear stress the material can hold before failing, C is soil cohesion, σ is the normal stress and φ is the angle of internal friction.

The strength or resistance to sliding at a soil-metal interface is analogous to the resistance to shear of a soil-soil surface. The soil-metal sliding equation (eq.2) is similar to the soil-soil shearing equation:

$$S' = C_a + \sigma \cdot \tan \delta \qquad (2)$$

Where, S' is soil-metal sliding stress, C_a is tangential adhesion, σ is the normal stress and δ is the angle of soil metal resistance.

In designing soil engaging implements it is of main importance to produce efficient tools, which perform the manipulation required with a minimum effort, therefore minimum draft. Parameters that influence the draft force required to pull or push the implement in the soil are: soil/soil parameters, such as angle of internal friction and cohesion, soil/metal parameters, such as polish of the implement surface and soil moisture content, both affecting tangential adhesion, and implement shape parameters. Between these, great importance assumes the rake angle, the angle between the horizontal and the implement blade (fig.6). Draft force increases as rake angle increases [8]. Moreover, during tillage, especially tillage in which the width of cut is very large compared to the working depth, a prism of soil is separated in front of the implement and slides forwards and upwards along the failure surfaces as the implement moves forwards (fig. 6).

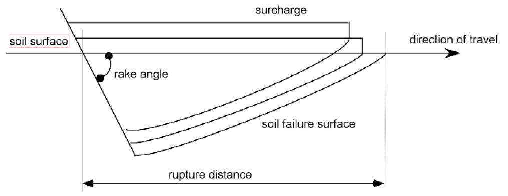

Fig. 6. Soil failure pattern and surcharge effect (adapted from Spoor [7]).

The failed soil associated with different failure surfaces build up in front of the implement producing a surcharge effect that is not desirable. This phenomenon can be attenuated if soil moves along the blade, i.e. if scouring occurs. Scouring occurs as long as the resistance at soil implement interface is less than at a parallel soil-soil interface. As generally the angle of soil metal resistance is less than the angle of soil internal friction, an increase in normal load improves scouring. Therefore, slatted implements with less surface area encourage scouring by increasing the normal load.

Low draft is a very important requirement also for the ground processing tool that is only one of the modules driven by the powertiller based tractor unit, a machine with only 7.5kW engine. For our application it is also important to increase scouring to have mines moved on the side of the machine.

In order to achieve an action similar to the one of heavy rakes and process the soil with minimum energy consume we have decided to design an implement with tines.

It consists of two tools: a single blade to cut the soil and tines to sieve soil away and retain mines. It is shaped like an arrow to allow landmines to move sideways from the machine lane. The rake angle is less than 90° to allow approaching the landmine from the side, avoiding exerting force directly on the pressure plate, as well as for lowering the draft force. The risk of actuating landmines exists, if landmines are found upside down or if soil presents a crust on top, but in case of explosion the damage to the tool should be limited to the tines, which are simple steel rods easily repairable at low cost.

There were two important implications in deciding the shape of the tool.

Weight transfer: most soil engaging tools involve a horizontal (draft) and vertical force (fig. 7). When the tool is mounted on the front of the tractor both of these forces, together with the weight of the tool, have the effect of transferring weight from the rear to the front of the tractor. These effects are generally undesirable (on a rear wheel drive tractor) and hence it is important that they do not become excessive.

Depth control: the requirement for good depth control is to avoid the tool working too shallow and missing mines or digging too deep and causing the tractor engine to stall or the tracks to slip. Mounting the tool on the tractor alone is likely to cause a variation in depth as the tractor pitches in the vertical longitudinal plane.

Therefore we decided to fit a depth wheel running in the undisturbed soil ahead of the tool (fig. 7). This reduces the weight transfer effect of the tool and assists in depth control. It is in the form of a cage wheel on the assumption that this will suffer minimum damage if a mine were to explode under it.

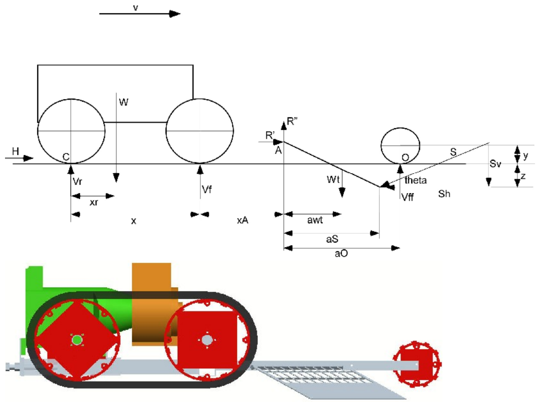

Fig 7. Weight transfer model and digital mock up.

Moreover, it is desirable, in the interests of simplicity, that the tool is formed from plane shapes. The simplest form of such a tool is therefore defined by two angles: the rake angle, between the tool and the horizontal (ground) in the longitudinal vertical plane, and a side angle, between the tool and the vertical longitudinal plane in the horizontal plane (fig.8).

Different low-fidelity prototypes with different rake and side angles were made and tested in a sand bed (fig.8).

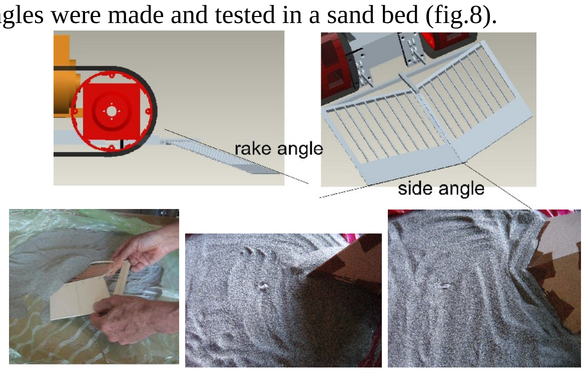

Fig 8. Ground processing tool definition angles and low-fidelity prototypes.

Tests showed that a small rake angle allows the soil to flow up the tool in a thin sheet and so encourages sieving, and a small side angle tends to cause the soil to be moved to the side and pass outside the passage of the tool width.

Therefore, to achieve mine disposal sideways, we adopted a side angle equal to 50° and rake angle equal to 30°. The rake angle had to be increased to keep the distance of the tool tip from the tractor unit relatively small.

The success of the tool in sieving soil and retaining or shedding mines depends on the form of the tool described above but also on the form of the sieve. Simplicity suggests that the form of the sieve members should either be in the plane of the sides of the tool, either parallel to the spine of the tool (effectively at the rake angle) or alternatively at the side angle (effectively horizontal). It would seem useful, in evaluative terms, to make one side of the sieve in one form and one in the other (fig.9). This would provide an immediate and obvious comparison of the two forms and guide future developments. As the tool will be tested in Jordan, distance between tines has been set to be less than 40mm, the minimum dimension of the smallest landmine M14.

It is understood that some form of active movement of the tool would assist in breaking clods and clumps and so improve the sieving process. This however should not be necessary in sandy soil for which the initial form of tool is being developed. However it is likely to be needed for future prototypes addressing other heavier soils.

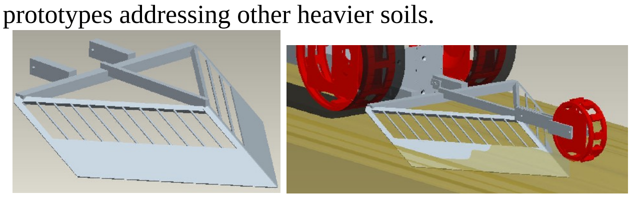

Fig. 9. Ground processing tool final design.

To calculate the draft force of the designed ground processing tool designed and compare it with the drawbar pull exerted by the tractor unit (3kN [9]), we used two different empirical models. In fact, the fundamental earth moving equation developed by Reece in 1965 gives the implement draft force as sum of four terms, respectively function of soil cohesion, surcharge pressure on failure surface, bulk density and tangential adhesion at soil metal interface. Each one of these forces can be calculated only if some soil parameters and dimensionless factors are measured in the field. Due to the impossibility to measure them in the field, we used a semi empirical approach.

From Agricultural Machinery Management Data, ASAE D497.5 FEB2006, published by the American Society of Agricultural and Biological Engineers (ASABE), the draft force, defined as the force required in the horizontal direction of travel for tools operated at shallow depths is given by eq. 3.

$$D = F_i \cdot [A + B(S) + C(S)^2] \cdot W \cdot T \qquad (3)$$

Where, D is the implement draft, F id a dimensionless soil texture adjustment parameter whose value is given in ASABE tables, A, B and C are machine specific parameters, given in ASABE tables, S is field speed, W is machine width, T is tillage depth. The value for the draft force necessary to push a tool, considered as a sweep plow in primary tillage, 1200mm wide, at 100mm depth, at 1.1km/h, in fine textured soil, is approximately 2.5kN.

A second estimation of the draft force of approximately 2kN was obtained extrapolating data regarding a 19 tine scarifier fitted with 150mm wide dart points [10]. In both cases, draft force of the ground processing tool is less than the drawbar pull exerted by the tractor unit.

A finite element analysis on the ground processing tool showed that steel plates 8mm thick are suitable to be used as plane shapes for the tool. With a horizontal load of 2.5kN applied on the spine and on side plates, the maximum stress induced, calculated with Von Mises criterion on the plates is less than 140MPa, while the maximum displacement is less than 4mm (fig.10). Yield strength for steel is 235MPa.

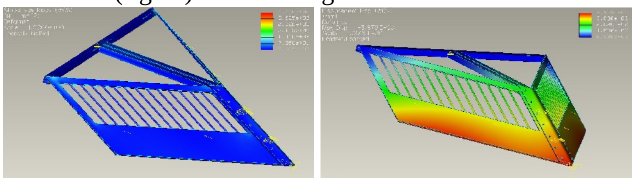

Fig. 10. FEM analyses on ground processing tool (steel plates 8mm thick).

V. SET-UP OF TEST FACILITY IN JORDAN

In the context of first author’s PhD a prototype of the tractor unit and remote control was developed and tested in Italy.

A collaboration with NPA Jordan and the University of Jordan made it possible to organize a test of the ground processing tool in realistic minefield conditions in Jordan, in March 2008. Unfortunately, time and money constraints don’t make it feasible to test the ground processing tool and the tractor unit at the same time, as resources and time are not enough either for developing a second prototype of the machine in Jordan or for transporting the Italian prototype in the country. Therefore, a facility for testing the tool has been set up in Jordan. Attention has been posed into the development of a system that could be used later on to test other ground processing tools targeting different soil conditions and compare results. In this way, more details on the performance of the ground processing tools can be understood and the design can be improved in possible further design iterations.

During a recent visit of the first author in Jordan, agreement for manufacturing the ground processing tool in the country was made. A mechanical workshop, located in Irbid in the north of the country, will manufacture the ground processing tool designed for less than 50US$. Test will take place in the Southern minefields at the boarder with Israel, under the supervision of NPA, in an area already cleared from active landmines. Already neutralized mines will be laid in the ground to observe their translocation at the tool passage. Real mines cannot be used as the prime mover of the ground processing tool will be a small tractor, hired in the country.

For connecting the ground processing tool to the tractor we will use a frame, attachable to the three point linkage hitch at the back of the tractor (fig.11).

As the tractor will be driven forward the ground processing tool will be pulled, not pushed as it will happen in real working configuration when mounted on the tractor unit. Therefore, the frame will have to provide a support similar to the semi mounted hitch in use in the machine. The ground processing tool rigidly connected to the depth control wheel has to be pivoted to a support that allows it to follow ground profile. For doing this we have chosen to employ a parallelogram frame, also called active frame, attachable to the three point linkage hitch, with a rear wheel.

Fig. 11. Small Jordanian tractor and its three point linkage.

The frame will be produced in the University of Jordan workshop and could be used later on for other tests. This particular structure allows the measurement of draft force using a force cell mounted horizontally between the linkage and the frame (fig. 12).

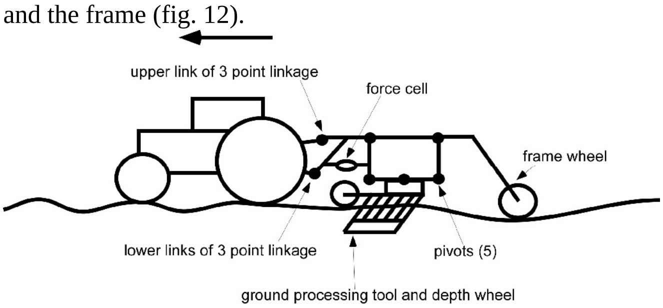

Fig 12. Ground processing tool frame mounting for test.

The forces acting on a general tillage tool act in a general direction in space and their measurement is complex and requires several transducers. However, when the tool is symmetrical about the plane of motion it is possible to simplify the system of forces by assuming that there is no force perpendicular to that plane, i.e. no side forces. The point of application and the direction of the single force left, in the plane of motion, are unknown, but they can be resolved in the plane of motion. The vertical component is pushing the tool into the soil and is resisted by wheels on the tillage implement; it does not contribute directly to the force required to move the tool through the soil. The horizontal component of the force, the draft force, is the one against which energy is expended. By an analysis of the static equilibrium of the frame it can be shown that if opposite members have the same length and the force cell is mounted horizontally, the force cell is measuring only the draft force [11].

The active frame presented could also be used for mounting the ground processing tool on the front of the tractor unit when a vibratory motion is needed to push it in harder ground. Where the force cell is now located a cylinder could be placed, providing horizontal forward and backward movement to the tool.

VI. FUTURE WORK

The test facility set up in Jordan will be hopefully re-used for testing new ground processing tools targeting different environments, soil conditions and landmines in the context of a new project whose proposal we have recently submitted to the Arab Science and Technology Foundation. The project aims at establishing a research centre of mechanical technologies for humanitarian demining in Jordan. There, we would like to employ the same participatory design methodology used for the rest of the work, to achieve more sustainable technologies.

ACKNOWLEDGMENT

The whole Participatory Agricultural Technologies (PAT) project could not have taken place without the help of the numerous wonderful people, who actually participate to it. Particularly, here, we would like to thank Professor H. Ross Macmillan of the University of Melbourne, who gave us precious support in the whole work regarding the ground processing tool design and test, Andy Smith who knows everything about the REDS system and has always followed the work from the field, Fabio Rossi who spent one week at the University of Genova working on the test of cardboard tools during his high school stage, and NPA Jordan for all the logistic support they give us. Last but not least we would like to thank Exilis Belgium for funding this part of the project.

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