

# Animal-drawn punch planters: a key technology for smallholder agricultural development in the 21<sup>st</sup> Century

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## Abstract

*On the eve of the 21<sup>st</sup> century the problem of mechanizing the planting process in small-scale agriculture remains largely unsolved worldwide. It is assumed that in Africa on average not even one farmer out of 1,000 is using a planter on the animal traction or tractor mechanization levels. Rough soil surfaces with imperfectly incorporated plant residues place great demands on planting techniques. They are the result of selective mechanization strategies. Minimum tillage is the standard procedure in systems using hand labour or animal traction rather than any special soil conserving measure. Labour requirements with regard to hand planting increases proportionally to the planting rate. For timely planting, farmers tolerate low (erosion-susceptible) plant densities and improper seed embedding. This results in low yields, which in turn affects farmers' willingness to adopt innovations. An animal-drawn planter has been developed which resembles the ancient method of manual punch planting (hand hoe or planting stick) in almost every step of the planting process. The principals of gentle seed metering and spot-like soil opening are retained. The transition from a discontinuous to a continuous mode of operation, however, reduces labour requirements by 80 to 90%. Unlike most conventional planters, it is able to cope with a cloddy seedbed and surface trash. Therefore, existing tillage practices need not be changed.*

*This paper commences with a review of common tillage and planting methods in Africa. Field experiments and on-farm trials were used to test the utility value of the animal-drawn revolving spade-punch planter (ADSP) compared to the traditional hand-planting method for maize in East Africa. In order to assess the feasibility of in-country production of the tool, parts of the machine were manufactured locally on a trial basis. The ADSP performed remarkably under an extremely wide range of seedbed conditions. It is a suitable alternative to manual planting in smallholder farming systems, especially with regard to yield dependability, productivity per unit area and soil conservation.*

## Introduction

Tillage and planting methods that reduce soil loss through wind and water erosion as well as water runoff produce or tolerate non-erodable obstacles on the soil surface such as stable soil aggregates (clods) and organic material (mulch). In the tropics and subtropics, the required quantities of crop residues for soil conservation can hardly be obtained and preserved on site. Thus, roughening of the soil surface through adequate tillage often remains the predominant way to control erosion. Planting at the right time, providing a fast and dense plant canopy, also protects the soil and optimizes the use of available water.

## Tillage on low mechanisation levels

The traditional slash-and-burn system works without any tillage. In permanent agriculture, however, the no-till system is usually only beneficial on so-called self-mulching soils with a minimum clay content of 20% (Charreau, 1977), in the presence of at least 2 to 4, or better 6 tons of organic mulch (Huxley, 1979; Lal, 1984) and in combination with chemical weed control (Phillips and Phillips, 1983). Where these requirements are not met, some kind of tillage is needed to increase soil aggregation and water

infiltration, to promote rooting, a rapid development of the plant canopy and to control weeds. Proper tillage then becomes a soil-conserving measure.

Looking at overall yield levels in the tropics and subtropics, it is unlikely that the required quantities of mulch for no-tillage can be obtained. The availability of crop residues is not only limited by the amount of rainfall but also by alternative uses, such as for livestock and fuel. But with good mulch management - the techniques are summarized in previous articles (Scheidtweiler, 1989; Scheidtweiler and Kromer, 1996) - at least intermediate solutions like paraplowing with the ard, rotational tillage every other year, possibly with semi-permanent ridges, strip or zonal tillage with strip mulching, etc. can be used to combine the benefits of both tillage and mulch (Table 1).

**Table 1: Reduced tillage in manual labour and animal traction systems**

Reduced intensity	Temporal reduction	Spatial reduction
no tillage: direct planting	single-pass tillage: plough-planting	on isolated spots: zonal tillage

only primary tillage: no multiple ploughing or harrowing	rotational tillage: alternating no-till and ploughing	in continuous lines: strip tillage
no soil inversion: paraplowing with the ard	rotational tillage: semi-permanent ridges	

**Table 2: Average seed spacing with manual planting of maize in Shinyanga region, Tanzania**

row width	0.84 m
distance between planting holes	0.59 m
planting holes per unit area	2.02 holes m <sup>-2</sup>
recommended planting density	4 - 7 holes m <sup>-2</sup>
seeds per planting hole	2 - 3 seeds

With low-level mechanization, minimum tillage is the standard procedure rather than any special soil-conserving measure. This is due to the limited power output of man and tropical draught animals as well as to the prevalence of heavy soils. Rough soil surfaces with imperfectly incorporated plant residues are very common. As conventional planters are not able to cope with such surface conditions, the mouldboard plough is often not just the first but also the only link in the mechanization chain.

The call for a smooth and residue-free seedbed through intensive tillage to facilitate further mechanization cannot be supported from the viewpoint of sustainable agriculture. On the other hand, the obstruction of further mechanization contributes to soil, water and yield losses, especially as a result of untimely planting and weeding. The same dilemma applies to no-till agriculture with large quantities of mulch. Thus, the actual challenge is the development of planting techniques, which are compatible with the existing methods of soil tillage.

### Furrow planting and punch planting

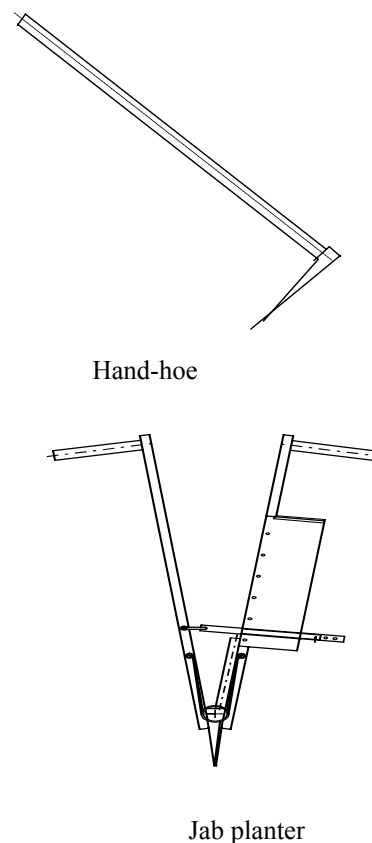
In order to give the crop a considerable growth lead over weed recurrence, farmers try to complete planting as soon as possible after tillage. For timely planting, they tolerate improper seed embedding and low plant densities. In the region, where this research was carried out (Table 2), and all over Africa, an average of only 20,000 planting holes per hectare is laid out for maize (Midohoe *et al.*, 1982; Nadar, 1984). In order to increase planting rates without additional labour, dibbling of two or more seeds per hole is practiced, even where certified seed with high germination rates is used.

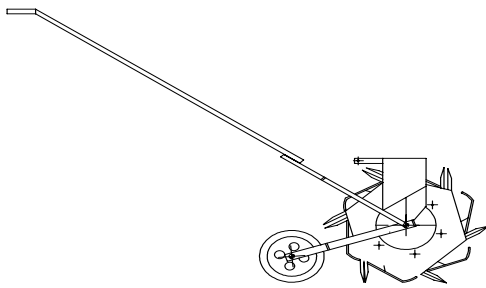
Irregular plant distribution adds to the susceptibility of soils to erosion and is one of the major reasons for low yields (East Africa: 1.4 t ha<sup>-1</sup>, [Statistisches Bundesamt,1994]), which are still at the level of the thirties in the United States. Therefore, the major requirements for small scale planting techniques are:

- They should be fast and perform well without discriminating against surface conditions and seed size.
- Low draught requirements are also important at the beginning of the rainy season, when draught animals are weak.

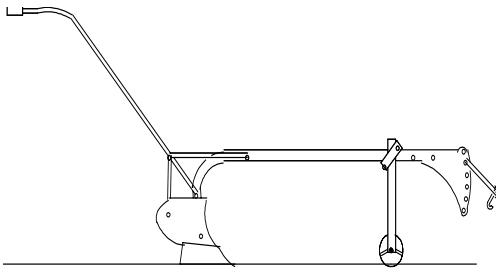
For sub-Sahara Africa the existing planting methods on the manual level as well as for animal-draught mechanization are summarized in Figure 1. This order at the same time conforms to another pattern of classification: the upper line consists of punch planting systems while the lower line consists of furrow planting systems. If energy is an important restraint, like with hand labour, the soil is not opened continuously along the total length of the field, but only where the seeds are eventually placed. This is particularly true on rough soil surfaces.

**Figure 1: Maize planting tools on the manual labour and animal traction mechanization levels in Africa (sub-Sahara)**

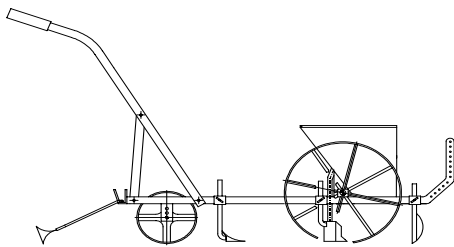




Rotary injection planter



Plough



Super Eco Seeder

The standard procedure for maize planting is punch planting with the hand-hoe. Jab Planters, Rotary Injection Planters, the plough-plant system and furrow seeders are employed on less than 5 % of the land under grain cultivation in Africa. On the threshold of the third millennium the problem of mechanizing the planting process on a small-scale remains largely unsolved, not just in Africa, but worldwide. Until recently, little research had been devoted to further developing the idea of punch planting and in the case of animal-draught mechanization, there are virtually no punch planters in use.

### Materials and methods

A completely new type of precision planter has been developed at the Institute of Agricultural Engineering at Bonn University (Kromer *et al.*, 1987; Shaw and Kromer, 1987; Eikel and Kromer, 1989; Eikel, 1991; Siebertz, 1991; Scheidtweiler, 1996).

The difference between the revolving spade-punch planter (ADSP) and common planting, animal-drawn

machines is the great similarity to hand planting. The ADSP is not a simplification or down-grading of modern technology but rather an up-grading of the traditional technique.

The striking feature of the double-row implement is the spade-wheels, arranged in a mirror image. Hollow wedge-shaped spades are mounted to the periphery of these wheels to penetrate the sod. The axis of rotation has a vertical inclination of 23° with an additional yaw angle of 7.5°. These angles create a combined vertical and lateral movement of the soil-engaging tools, very similar to the way a hand-hoe works. As the soil is opened spot-like, there is no risk that a furrow can induce rill erosion.

Each seed-metering device is equipped with an inclined cup-feed wheel and a star-feed disc. Single seeds with a wide range of callibers are gently scooped from the reservoirs as if by hand.

Data are available from farming-systems research, field trials and on-farm tests to compare the ADSP with manual punch planting of maize. This was done during the years 1991 and 1994 in the Shinyanga region of Tanzania (3°2' S, 33°4' E, 1.143 m). The suitability of both planting methods for direct planting through mulch was also investigated. Another factor was the planting time. The factor complex was repeated on two sites over two years. The Vertisol at site "A" is a loamy clay soil with a sand content of only 2 %, while the Oxisol at site "B" is a sandy loam soil with a sand content of 52%. Tilling was carried out with an animal-drawn mouldboard plough. Compared to the no-till treatments ploughing reduced the degrees of mulch and weed cover from about 60% to between 5 and 20 %.

The climate in Shinyanga is semi-arid with an average annual precipitation of 820 millimeters. 90% of this rainfall occurs between November and April. The variability in distribution and amount of rainfall is extremely high, with almost every year being abnormal. Consequently the risk tolerance of farmers is very low. Inputs that are exclusively directed at an improvement of yield levels and not at an improvement of yield reliability will hardly be accepted here.

### Results and discussion

The main effects of both planting techniques are summarized in Table 3. The ADSP was superior to manual planting with respect to the accuracy of (horizontal) seed placement, initial and final seedling emergence, accuracy of plant spacing and grain yield. As far as uniformity of planting depth and covering height (vertical seed placement) and the uniformity of

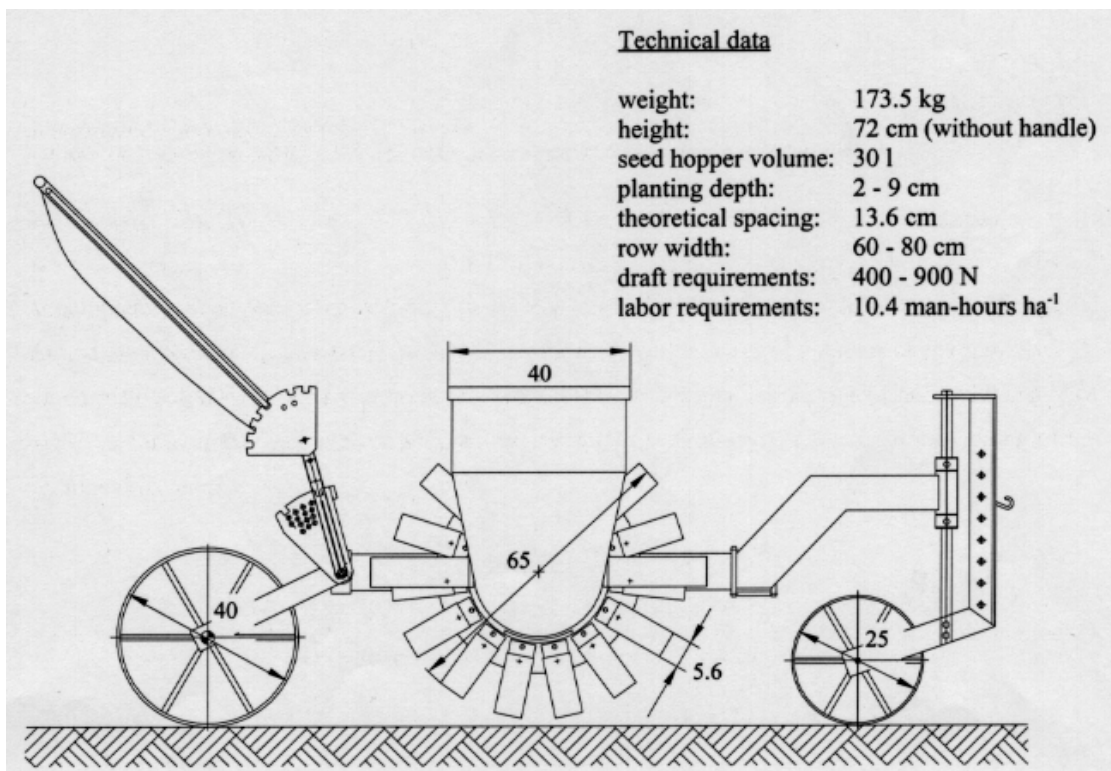
plant distribution is concerned, the ADSP did not differ significantly from the traditional method.

With regard to the avoidance of doubles and voids, hand planting is superior to every planter without competition (Scheidtweiler, 1990). The distance between planting holes, however, was considerably higher than with the ADSP (38.9 cm vs. 13.9 cm) as the soil from the holes had to be deposited temporarily in-between the open planting spots. This is another reason why high plant densities are usually to be found where farmers do not practice thinning and tolerate irregular plant distributions. In the trials two seeds were planted per hole, as is common

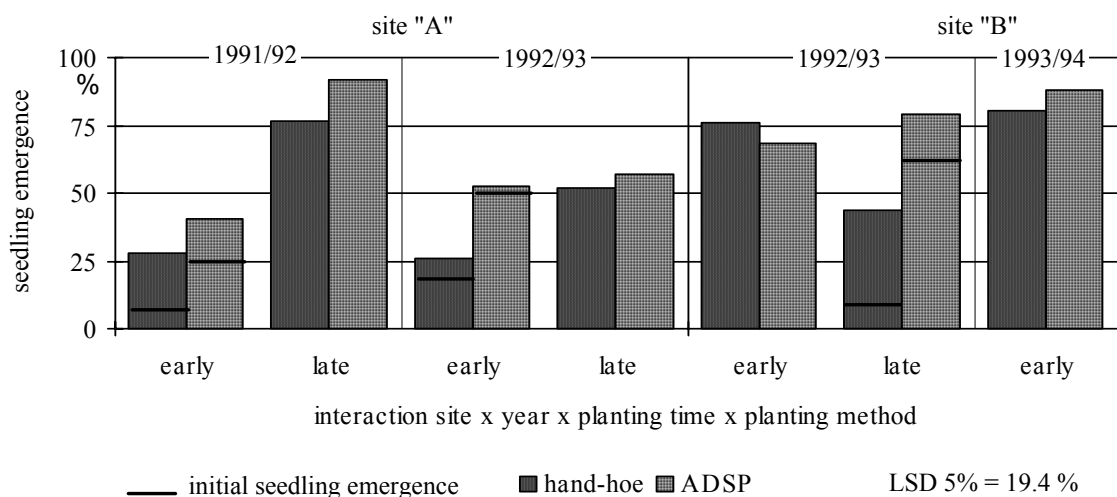
practice. Later on, the distances between plants in the manually as well as in the mechanically planted plots were leveled out to about 40 cm through thinning.

Depending on the prevailing regime of precipitation, seedling emergence varied considerably at between 26 % and 92 %. Under favorable rainfall conditions the seedlings emerged within five days after planting, i.e. initial and final seedling emergence were equal. A low emergence velocity (low initial seedling emergence rates) always resulted in poor final emergence rates because germinating grains were damaged by insects and draught.

**Figure 2: Animal-drawn revolving spade-punch planter (ADSP) with technical data**



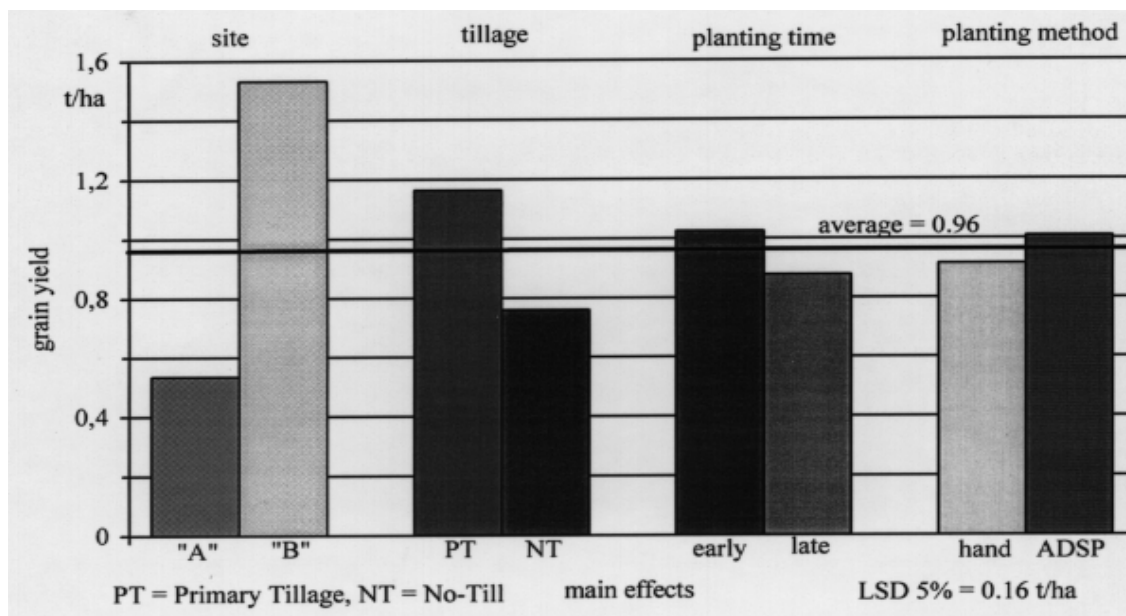
**Figure 3: Seedling emergence rates on tilled plots**



**Table 3: Main effects of the planting method factor**

Parameter (DEG 1989, 1993; ISO, 1982)	hand-hoe (%)	ADSP (%)
Accuracy of lateral seed placement (required spacing $\pm$ 2 cm)	38.1	<u>74.9</u>
Uniformity of horizontal seed placement: seeds at 0.5 to 1.5 times the required spacing (others are voids and doubles)	<u>96.8</u>	84.3
Uniformity of vertical seed placement: Coefficient of variance, planting depth*	28.0	29.2
Coefficient of variance, covering height*	41.5	44.0
Initial seedling emergence rate* (25 % of the planting rate)	43.5	<u>57.8</u>
Final seedling emergence rate*	55.8	<u>65.2</u>
Accuracy of plant distribution (required spacing $\pm$ 3.5 cm)	41.5	<u>80.0</u>
Uniformity of plant distribution: plants at 0.5 - 1.5 times the required spacing*	63.8	64.3
within-the-row spacing: hand-hoe (2 seeds per hole) 38.9 cm, ADSP (single seeds per hole) 13.9 cm		
* significant interaction with at least one other factor      __ significant main effect (superiority)		

**Figure 4: Main effects of the trial factors on grain yield**



Manually planted maize proved to be highly sensitive to an irregular water supply. This is due to improper seed imbedding: Farmers usually move stable soil aggregates over the seed with one foot. Water transmission from the soil to the seed can not take place until clods disperse under the impact of rain. Therefore the success of manual planting is governed by weather conditions and planting time. The ADSP established good seed-to-soil contact and made better use of scarce soil water. It compensated a higher percentage of seed voids (the only parameter where hand planting was superior) for better seedling emergence rates, resulting in an overall equal percentage of plants at the required distance.

The analysis of the planting time factor indicates that it is not so much the total amount of rainfall, but

rather the frequency of rains which determines the seedling emergence rates. With high evaporation, sufficient soil water in the shallow germination zone will only be available if several successive rain showers take place after planting. At the very beginning of the rainy season this usually does not occur. It would be advisable to plant during a high rainfall frequency and not necessarily as early as possible (which is the usual recommendation). Such a strategy, however, requires a higher rate of work than is available with hand planting.

Grain yields were highly dependent on physical soil properties. Particularly at site "A" the detrimental effects of unabsorbed surface water alternated with the effects of severe water shortage. Ploughing improved the hydraulic properties of both soils and

diffused the weed problem. This resulted in yields which were on average 54% ( $0.4 \text{ t ha}^{-1}$ ) higher than those under direct planting. The ADSP plots yielded on average 10% more than the manually planted variants.

The yield increase would have been much higher if the plant populations had not been standardized by thinning, because in that process many more plants (40%) had been removed from the ADSP plots than would have been made necessary by the capacity of the sites. This was confirmed in the on-farm trials. The best factor combination was mechanical planting with previous soil tillage. Here seedling emergence rates of more than 92% (late planting 1991/92 at site "A") and grain yields of up to  $2.6 \text{ t ha}^{-1}$  (early planting 1992/93 at site "B") were achieved, which comes up to the highest possible yield expectation for "Katumani Composite" maize in Shinyanga.

As opposed to the ADSP, labour requirements with regard to hand planting increase proportionally with the planting rate. With the common planting rates of 20,000 holes per hectare, the mean labour requirements were  $62.3 \text{ man-hours ha}^{-1}$ . In the experiments they were  $109.6 \text{ man-hours}$  with 36,630 holes per hectare. Labour requirements for the ADSP, with a row width of 0.7 m, were  $10.4 \text{ man-hours ha}^{-1}$ . Now two persons could finish off all the maize planting (1.2 ha) on an average-sized farm (3.8 ha) within a single six-hour day. With direct planting the time and energy required for weeding was equivalent to extensive tillage with the hand-hoe. Thus, the intensity of soil tillage and labour was not reduced by not using the plough, but only delayed.

The mean draught requirement to pull the ADSP is 650 N. This is significantly lower than the value for ploughing and corresponds to the permanent draught force of two local oxen at the end of the dry season. Farmers assessed the handling of the ADSP using 12 criteria and felt it was easy to operate as a whole. However, it was difficult to keep the machine in straight lines if the oxen are not well trained.

Various grains, such as chick-peas and groundnuts, can be easily planted with the ADSP maize metering devices, which need not be changed for such crops. Simultaneous planting of two different crops (inter-cropping) and sowing of tree seeds like *Leucaena leucocephala* was also successfully performed in agro-forestry trials.

As there is no reliable distribution network for spare parts in Tanzania, a local industrial company was hired to reproduce a planting unit, the most sophisticated part of the tool. The product provided remarkable evidence that local production of the machine is technically feasible. If produced domestically, the complete machine costs about US\$ 1,000. This is a lot of money for the farmers in question. However, in contrast to a widespread opinion it is not so much the price, but rather the performance and practical value of an innovation, which determines its acceptance. There are numerous medium-scale contractors for animal-traction, who showed great interest in the ADSP. For years the prototype has been employed to plant approximately 50 ha every season.

#### Summary and conclusions

The traditional method imposes limits on plant densities which are below minimum. Plant densities are 40% higher with the ADSP, which places single seeds in every hole instead of dibbling. This makes better use of the yield capacity of the soils. Also the efficiency of soil water use during the critical germination period was enhanced through the new technology. This was manifested in seedling emergence rates, which were on average 10 % above those of hand planting.

The traditional method holds out a high uncertainty for cultivation depending on the planting time due to poor seed-to-soil contact.

time factors ( $\text{man-hours ha}^{-1}$ )	Manual planting		ADSP
	on-farm (FSR)	field trials	field trials & on-farm tests
productive time	45.8	84.3	5.0
preparation time	0.8	1.5	0.7
traveling time	1.7	2.9	0.7
ineffective time	14.0	20.9	4.0
total labour requirements	62.3	109.6	10.4
rate of work ( $\text{ha h}^{-1}$ )	0.03	0.02	0.19
working days per farm	3.0	5.3	1.0
( $\varnothing$ 1.2 ha maize)	(4 persons)	(4 persons)	(2 persons)

The planter makes another contribution to reducing the risk of farming through its high work rate and great efficacy. The tolerance of a wide range of seed calibers and seedbed conditions are additional factors where the ADSP distinguishes itself from other planters in Africa, though not from hand planting.

Small-scale contractors and machinery pools can get an adequate return on investment with the ADSP. Although investment requirements are relatively high, the ADSP has good chances of being accepted, as there is no other implement on the market, that combines all the proved benefits in a single machine:

- higher planting rates with more uniform seed distribution (increase in output per unit area)
- higher efficiency in exploiting soil water for germination (decrease in farming risk)

- low labour and draught requirements (increase in labour productivity)
- tolerance of a wide range of seed calibers (gentle seed metering, versatility)
- suitability for corrugated soil surfaces and for mulch planting (soil and water conservation)

The ADSP increases sustainability of farming. Working on rough soil surfaces and mulch, it provides a fast, uniform and dense plant canopy to protect the soil. This also improves the efficiency of tillage with respect to weed suppression and enables farmers to keep the weed problem under control without herbicides. Lastly, higher yield expectations encourage the acceptance of further innovations to increase the sustainability of agriculture in developing countries.

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