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Mechanization's Contribution to High Level Sustainable Production - from Tillage to Mechanical Weed Control.

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1 Introduction

World agricultural food - and non-food production has to grow year by year at a rate of about 3 %, but we have to be very careful with the environment and productivity especially in cases of fragile soil systems like in the savannas. Even nature does not guarantee a permanent sustainability as can be observed, for instance, by the history of climatic changes in all parts of the world. The level of agricultural production - from subsistancy to cash crop surplus - has a strong impact on regional attractivity, economy and settlement.

A high level of regional productivity means a demand for labour, not only in the agricultural production but also in production, marketing and maintenance of inputs (like fertilizer or machinery) and in the post harvest sector. In the case of the 200 million hectares Cerrado areas of Brazil, this means attractivity and migration towards these remote areas - decentralization for Brazil. Soil degradation, on the other hand, means not only environmental deterioration but loss of the agricultural basis - exodus of rural population to coastal and urban centres like Belo Horizonte, Rio de Janeiro or Sao Paulo.

In agricultural production man-made problems and catastrophes like compaction and erosion or pollution, are unfortunately well-known phenomena. Inadequate mechanization and especially inappropriate tillage was often the main reason. CIAT expresses the potential of the Latin American Savannas to be either "dustbowl or ricebowl". Discussions are increasingly polarized between intensified production on limited areas under favourable soil and climatic conditions, using all necessary and economically viable inputs on one side, and reduced production intensity (naturalization) on low input base on the other side. A CIAT-initiated undertaking with EMBRAPA participation called "Management of Acid Soils (MAS)" focuses on the development of appropriate technologies for sustainable management of soil and water resources in the savanna region as well as other places[1].

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Whatever sustainability in agricultural production may be, basically we have to study and to regard material flow and to control and manage the cycle of water, nutrients and organic matter or carbon to increase production and to allow safe yields at a high level for generations.

Mechanization can serve the target of sustainable production by situation appropriate, target orientated technical means on any technical level - from handhoe to global positioning systems (GPS)-controlled, self-propelled machinery and can help to optimize efficient use of resources to improve input/output relations. Regarding ecological aspects like erosion or pollution in sensitive areas, new technologies are available like direct drilling, for instance, or substituting diesel oil with plant oil as fuel, using biodegradable plant-oil-based hydraulic oil in farm and forestry machinery and fishing boats on rivers and lakes or by substituting herbicides with improved methods of mechanical weed control.

But each production system, each individual field activity and each tool or implement within the system has to be checked for its effects on soil function and internal cycles with an interdisciplinary effort.

2 Soil Functions and Organic Matter

To maintain soil productivity and to prevent soil degradation on one side and to minimize cost on the other side, we have to plan tillage carefully and to bear in mind soil functions which control the mentioned cycles and which technologically can be described as functions of

store:	mainly for water and nutrients
filter:	to fix or accumulate clay minerals, nutrients and organic matter and to allow surplus water to drain
reactor:	to allow mineralization , for instance,
foundation:	holdfast of plants and base for traffic

Organic matter, like straw or catchcrop, but especially compost, not only is a main key to activate these functions but controls together with water content, the aggregate stability and technological properties like trafficability and workability of soils (fig. 1) as well as phytosanitary effects.

Organic matter widens the distance between shrinkage and plasticity limits and that means the time available for optimal workability with minimal energy demand increases, showing good effect and little negative side effects. But especially in the savannas availability of organic matter is the problem to hold, or if possible, to increase the necessary carbon content level in the soil.

The effect and the rate of demineralization of organic matter depends on timeliness and humidity, on bioactivity of the soil and on the localization above surface - shallow or deeply incorporated. Especially in irrigated systems with permanent humidity and high temperatures like in the tropical savannas, the rate of decomposition is very high. Animal dung, due to tropical animal holding systems, is hard to be collect and distribute for arable land. So crop rotation, cereals with the straw left in the field, and mainly catchcrops gain importance to produce carbon (and possibly nitrogen as well).

All resources - like manure, sewage sludge (with heavy metal content below limits of tolerance), compost from agroindustry (from bagasse or oilmeal) or from households - as far as available - should be included, processed and recycled.

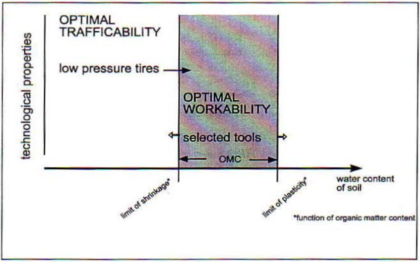

Fig. 1: Technological Properties of Soil [Author]

In the case of savannas, composting, despite heavy losses of nitrogen, has to be preferred compared to stockpiling and direct application because of the long-term effect on soil functions rather than the short term nutrient contribution [2]. Beside hand operation, compost mixing and inversion equipment for great volumes is available (fig. 2). Last but not least, by mulching organic matter the soil can be efficiently protected against wind and water erosion [3]!

For households with scarce resources, in order to avoid greater inhomogenities in the soil and because of environmental effects, exact dosage and equal distribution of organic matter are necessary as well as the possibility of year around field application, even as top dressing. Therefore my department has recently started a project to develop a compost spreader with automatic-radar-controlled, speed proportional rate of delivery and exact transversal distribution over 12 m working width, for controlled traffic in growing crops.

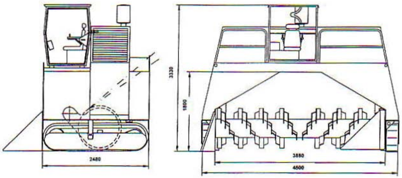

Fig. 2: Self propelled compost dam processing machine (side- and frontview) [4]

Coming back to the discussion of low or high production intensity, different environment effects have to be discussed. High yields require adequately high inputs of fertilizer. Because high rates of (mineral) fertilizer application are responsible for an increased laughing gas (N_2O) emission, fertilization should be strictly demand - and target-orientated. Electronic control for operationspeed -proportional - rate of delivery is available [5], including plot specific application via global position control (GPS [6]). Above this late research demonstrates that there is an increase of CO_2 emissions per area with increased production intensity but there is no increase of CO_2 emissions per unit of weight of yielded crop [7]. Above this, high yields of cereals , for instance, also mean high yield of straw and root mass which again improves the carbon content in the soil with the mentioned positive effects. So even aspects of ecology and sustainability might be in favour of an increased cropping intensity instead of further extension of the area.

3 Tillage

The less tillage we do, the slower the breakdown of organic matter and the more likely organic matter levels can start to build up [8]. An undisturbed soil surface above this - especially when covered with a mulch layer - is less sensitive to erosion.

On the other hand traditional deep tillage and seedbed preparation aim at an optimal pore space (42 to 45 %), pore size distribution and a seedbed with a functional capillary system up to the seedling, a fine structured seedbed for heat transfer and gas exchange and a crumbled top layer to reduce evaporation. Heinonen shows a minimum of evaporation at an average mean aggregate diameter of 0,5 to 5 mm [10] and especially dry regions need a fine crumbled seedbed for water availability. But exactly this size is susceptible to erosion (fig. 3)!

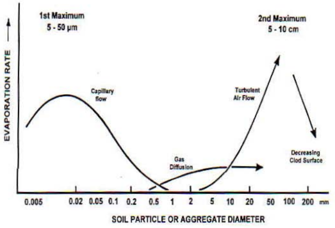

Fig. 3: Evaporation rate as a function of soil particle size [10] Above the aim of optimizing soil structure any tillage operation aims at weed control.

So, after a specific session of this symposium devoted to "Zero tillage", I will focus on reduced tillage and conservation tillage aiming at:

TARGET ORIENTATED TILLAGE
AND THE MINIMUM NECESSARY

From the technical point of view we have to clearly define the target of operation and to watch for possible uncontrolled negative side effects (fig. 4) like the potential of erosion or of crusting as possible consequence of fine crumbling. To minimize soil movement we will discuss separately intensity, depth and frequency of tillage and how to reduce each of those parameters to the necessary minimum.

We have to decide on whether to invert the soil or not and whether to deeply or shallowly incorporate and mix organic matter and soil. In the case of the savannas I think we should generally avoid inversion and we should incorporate organic matter only in case of high rates of application to accelerate decomposition and to give an incentive for deep rooting, using it mainly for surface protection [3], being aware that possibly we can create a declining OMC content from top to bottom which is hardly to be compensated for by growing root mass (only in native savanna plant population we have this phenomenon of "underground forests").

World-wide there is a wide range of individual and combined implements available for all levels of mechanization, drawn and PTO-driven, with inversion, incorporation, mixing, loosening, recompaction or surface forming effects. But most of the tools and implements do not focus on one effect only. They should be selected according to the well defined target of operation and according to the situation - and that means, for instance, the high degree of adhesion of soils on metal surfaces of tools.

target orientated primary mechanical effects	more or less uncontrolled secondary effects	
loosening	erosion	
crumbling	clogging and crusting	
mixing (horizontal, vertical)	compaction	
incorporating	salination	
turning over	loss of	water
crust breaking		nutrients
compacting		organic matter
levelling		
dam forming		
hoeing		

Fig. 4: Effect and side effects of tillage [Author]

Smaller farm holdings, for instance, with access to heavy tractors and advanced technology, at least in Europe, use a combination of drawn tine- and rotating, PTO-driven implements. This is often also combined with seeding to reduce the number of field operations. However, the necessary efficiency on large fields is only reached by drawn implements with adequate width and speed of operation.

Within an extended crop rotation system, crop-specific tillage is necessary to minimize depth and frequency of intensive tillage. So after manioc, for instance, there is no necessity for deep tillage (only once within a crop rotation). On the other hand, research at ICRISAT Niger show clearly that furrowing in sorghum production can increase yields up to four times due to reduced wind erosion [11]. Vogel and his team proved tied ridging to be most successful in preventing erosion and water harvesting in Zimbabwe [12]. Suitable implements to achieve this are available at all levels of mechanization.

New approaches demonstrate that yields obtained using mulch technologies (with and without seedbed-preparation) are not necessarily reduced because proper positioning of seed with new seeding technology is possible [13] - even without preceding stubble mulching. Compared to disc shares, tine shares (fig. 5) allow a lighter share, better penetration, controlled depth and good seed-soil-contact, better loosening and mixing, (which might lead to improved gas exchange), heat transfer and infiltration, but could increase water loss as well as increased problems with clogging.

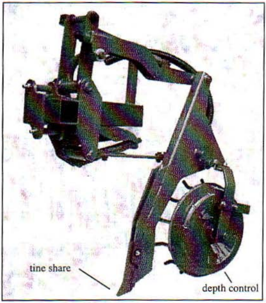

Fig. 5: Parallelogram guided direct drill machine unit [14]

There is a tendency to reduce the depth of tillage operations to allow the formation of a naturally grown, stable soil structure and also because each centimetre of tillage depth costs up to two litres of diesel oil. It has been shown that even compaction to a certain degree at a certain level under the seedbed - provided there is a sufficient number of vertical cracks and left root canals, and therefore a stable poresystem - is tolerable. Special implements to artificially create the necessary vertical pores or slots are recommended [15]. This stratification leads to an improved trafficability of soils and that means better timing of field operations [13]. So deep tillage, at least from this point of view, can be eliminated, provided soil functions are sufficient and there is no demand for deep incorporation of organic matter, positioning of immobile fertilizer or lime or turning up down washed clay minerals. But this in reality often leads to the necessity of intensive tillage measures, at least from time to time. In this case the swing plow (fig. 6) might be a good choice - at least for light, brittle soils which are not too much threatened by erosion - because of sufficient effect, low weight and cost and because of its advantages of reversible plows on smaller plots. If only loosening is necessary there are "soft" implements available for conservation tillage like the paraplough (fig. 7). But the timing of loosening operations is as important as selection of the suitable tool. The effect depends on the watercontent of the soil (within workability limits over the whole depth). After loosening, soil is highly sensitive to recompaction, so that it is necessary to prevent heavy traffic on lately loosened soil and to stabilize the effect by fast and deep rooting vegetation.

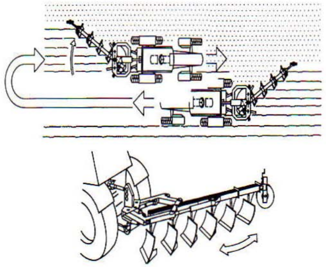

Fig. 6: Swing plow [16]

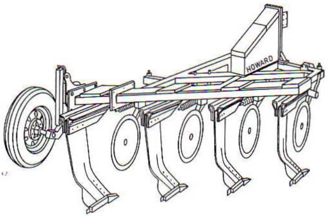

Fig. 7: Para plow [17]

4 Weed Control

Weeds are responsible for substantial yield losses [6] (fig. 8). FAO believes weed management to be one of the main challenges in plant production [17]. The cost of weed management, according to our own investigations, often exceeds 30 % of total production costs. More attention has to be devoted to prevention of weed infestation. So all sources of weeds have to be investigated and limited as far as possible to finally reduce the weed seed bank in the soil (fig. 9) [18].Tillage, besides controlling soil structure, is a very efficient means of weed control, mainly pre-plant tillage. Less tillage normally causes more weeds. Zero tillage generally causes a severe weed problem, and weed management gains importance.

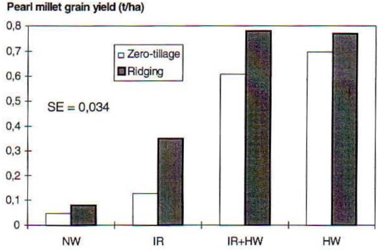

Fig. 8: Interaction effect of presowing ridging and weeding method on pearl millet yields.- Average of two cultivars over 3 years at ISC. NO = no weeding, IR = interrow weedings, HW = hand weeding [11]

Ecological agriculture forbids the application of herbicides generally and also conventional agriculture looks for alternatives because of cost, efficiency, resistance and regional limitations of the application of herbicides because of negative environmental effects. So beside crop rotation, cover crops - which seem to be very efficient in the Savanna for weed control as well as for nitrogen fixation - and other biological methods of integrated plant protection and weed control, mechanical control is used. In this respect, most of the ecofarmers in Germany believe the plow still to be indispensable, especially when combating perennial weeds, but they plow very shallowly to save energy, and, if necessary, in combination with loosening tools under the plow share and of course not every year and not to every crop of conventional agriculture.

In mulching systems total herbicides, before or after seeding, are commonly used and believed to be indispensable. Spraying technology shows great progress generally in improved target orientation (in cereals as well as in fruit production) (fig. 10). These techniques employ GPS or at least - as a first step in row crops - a combination of mechanical devices as an additional way of reducing herbicide application by plot specific dosage [19] interrow weeding and band spraying in the rows. Especially in the vast fields and plots of the Cerrado-areas, GPS controlled devices distribute specific applications of herbicides in response to the rapidly changing weed population.

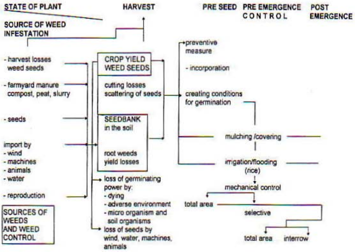

Fig. 9: Sources of weed infestation and weed control [Author]

Recent research attempts to further our understanding of mechanical weeding, to look for combination of mechanical and chemical weed control or even to totally remove the need for chemicals in row crops [20] and even in cereals by using improved soil and P.T.O. driven tools. The rotating hoe (fig. 11), well known in cotton production for weed control as well as for crust breaking and furrowing, proved to be efficient in other crops, especially in combination with hoeing tools because of its high field efficiency.

Wider row spacing of cereals in tropical and subtropical dryland allows easier mechanical weed control. In fruit and vegetable plantations slashing of weeds and leaving the slashed matter as mulch prevents damage of shallow root systems and helps to control erosion. Comparatively recent investigations show comparable results between pure mechanical and pure chemical control, even in cereals and at lower cost than chemical control (fig. 12) [21].

The most difficult task is to control in-row-weeds in row crops mechanically. A device is being developed for this, which will use transversal soil transport of between row-tools or plant identification sensors and active driven hoeing tools (fig. 13) [22].

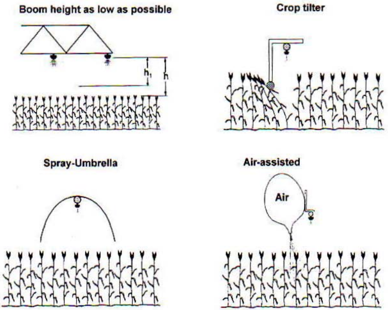

Fig. 10: Reduction of drift losses in field application [9]

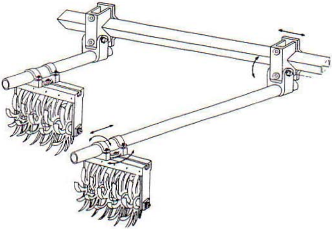

Fig. 11: Rotating hoe [21]

For sustainability, two further aspects should be considered:

- the necessity of identifying tolerable limits of weed populations, taking positive effects of weeds and biodiversity into consideration and
- effects of weed control on soil structure.

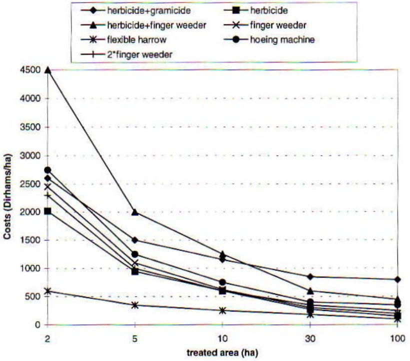

Fig. 12: Effect of method of weed control and size of treated area on cost (wheat production in Maroc) [21]

It is well known that mechanical hoeing initiates mineralization and affects the cycles of nutrients, water and organic matter.

In the case of sprinkler irrigated heavy clays in North Africa great differences in aggregate size and infiltration rate were shown, using different implements (fig. 14 and 15). Here - I believe - is still a demand for further research in the tropical savannas.

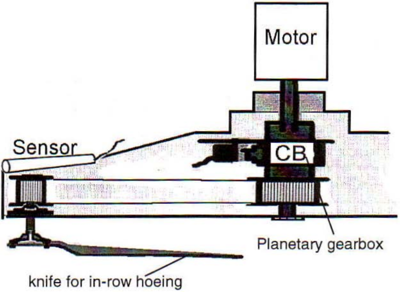

Fig. 13: Sensor controlled active hoe for in-row weeding [22]

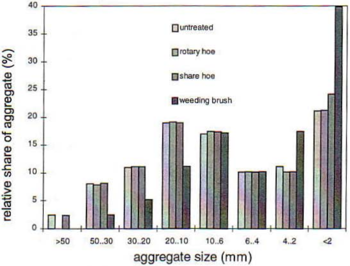

Fig. 14: Distribution of air dry aggregate size classes in the top soil after different implement applications [20]

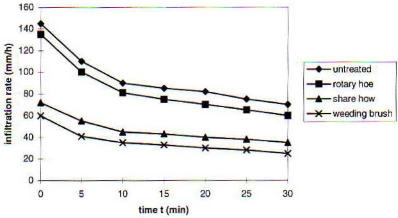

Fig. 15: Reduction of water infiltration rate into soil with irrigation time according to different implement applications [20]

5 Summary

Sustainability in agricultural production is not necessarily the consequence of the level of production intensity. Of major importance - beside sociological and economical aspects - is the productivity of the soil and this means the continuity of soil functions where are mainly determined by the organic matter content and on the cycles of nutrients and water.

Modern technology, alongside traditional tools and implements, offers a wide range of equipment for the different field operations with increasing precision. An important aspect is the sensitive and situation appropriate selection and utilization of farm machinery to improve the input/output relation, to save energy and resources, to reduce the use of chemicals by either substituting them or by demand and target orientated application and to control and reduce negative side effects, aiming at our common target: Sustainability at a high level of productivity.

Beitrag der Mechanisierung zu einer nachhaltigen Pflanzenproduktion im Cerrado Nord-Westbrasiliens

Zusammenfassung

Nachhaltigkeit in der Agrarproduktion ist nicht unbedingt an ein niedriges Produktionsniveau gebunden. Entscheidend - neben soziologischen und ökonomischen Aspekten - ist die Pflege der Bodenfruchtbarkeit. Das bedeutet, die Erhaltung der Bodenfunktionen, die in hohem Maße von dem Gehalt an organischer Masse und von dem Luft-, Wasser- und Nährstoffhaushalt abhängen.

Moderne Technik bietet neben traditionellen Werkzeugen und Geräten ein weites Spektrum an Maschinen für die verschiedenen Feldarbeitsgänge. Wichtig ist die sensi-

ble und situationskonforme Auswahl und der Einsatz zur Verbesserung der Input/output Relation, zur Einsparung von Energie und Ressourcen und zur Verminderung oder Vermeidung des Einsatzes von Agrochemikalien, indem sie entweder substituiert oder zumindest mit hoher Präzision bedarfs- und zielgerecht eingesetzt werden.

Beispielhaft werden Geräte und Strategien aus dem Bereich der Kompostbereitung, der Bodenbearbeitung, der Sätechnik und der Unkrautkontrolle vorgestellt und auf Nebenwirkungen hingewiesen.

La contribution de la mecanisation pour une sustainable production des plantes dans le Cerrado au nord -l'ouest Brésil

Résumén

La notion de durabilité dans la production agricole n´entraîne pas forcément une baisse du niveau de production. A côté des aspects sociologiques et économiques, il est important d´entretenir la fertilité du sol. Cela signifie qu´il faut maintenir les fonctions du sol qui dépendent en grande partie de la tenance du sol en matières organiques et de l´équilibre en air, en eau et en substances minérales.

Les techniques modernes offrent aujourd´hui, en plus des outils traditionnaux, un large éventail de machines pouvant servir au cours des différentes phases de travail du sol. Il est particulièrement important d´adapter les méthodes de travail aux conditions des sols et d´utiliser le matériel avec pour objectif l´amélioration de la relation d´entrée et de sortie des ressources du sol et la réduction ou la suppression de tout intrant chimique. Pour cela il faut les substituer ou au moins essayer de les utiliser avec une plus grande précision suivant les besoins et le but.

Ce dossier présente les possibilités d´insertion et les conséquences d´utilisations de différents outils et stratégies de travail dans le domaine de la préparation du composte, du travail du sol, des techniques de semence et du controlle des herbicides (mauvaises herbes).

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