ISSN 0084-5841

AMA

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

VOL.38, No.2, SPRING 2007

FARM MACHINERY INDUSTRIAL RESEARCH CORP.

International specialized medium for agricultural mechanization in developing countries

ISSN 0084-5841

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Vol.38, No.2, SPRING 2007

Edited by

YOSHISUKE KISHIDA

Published quarterly by

Farm Machinery Industrial Research Corp.

in cooperation with

The Shin-Norinsha Co., Ltd.

and

The International Farm Mechanization Research Service

TOKYO

Potential for No-Tillage Agriculture in the Pandamatenga Vertisols of Botswana

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Abstract

The objective of this paper was to conduct an extensive literature review to assess the status and potential of no-tillage as an alternative tillage system on vertisols in the Pandamatenga farms, Botswana. Farmers in the area have failed to produce satisfactory crop yield levels because of problems associated with management of the soils using conventional tillage systems.

Information from literature showed that no-tillage system was effective in improving soil quality, water management, and crop yield in the area. However, there is a need to carryout in-field trials to monitor changes in the soil quality and the environment under no-tillage and conventional tillage systems.

Introduction

Pandamatenga region lies in the north-east fringe of Botswana between latitude 18º 26' to 18º 43' South, and longitude 25º 27' to 25º 37' East (**Fig. 1**). The Pandamatenga region covers a land area of 280,380 ha. The Pandamatenga farms covers only 25,074 ha of this total land area.

The area is generally flat, with a gentle slope, and rain water flows following natural drainage routes. The vegetation is extensive grassland savanna in association with mophane (Colophospermum mophane) and Acacia species.

The climate is subtropical with hot, rainy summers and cold, dry winters. The mean annual rainfall is 626 mm with annual totals varying between 394 and 1,050 mm. A substantial proportion of rain falls between October and April in short duration high intensity storms.

Vertisols such as the ones found in the Pandamatenga region are considered good farming soils, but they have unique properties that require special management if full yield potential is to be realized. Most commercial and small-holder farmers in the Pandamatenga region practice conventional tillage to grow sorghum (Sorghum bicolor L.), sunflower (Heliantus annuus L.), and occasionally cotton (Gossypium sp.). Under conventional tillage system, the whole field is ploughed using either a moldboard or disc ploughs followed by 1 to 2 harrowings before seeding. This system destroys soil structure leading to problems related to soil degradation (Gupta et al., 1989) and compaction. Soil compaction is caused by high field machinery traffic as well as continuous cropping that result in an increased exposure of soils to high intensity storms (Kayombo and Lal, 1993). The long-term effect is the decline in crop yields (Yao-Kouame and Yoro, 1991).

Problems of accelerated soil erosion, high costs of energy inputs, and low yield returns associated with conventional tillage methods of seedbed preparation have led to increasing adoption of no-tillage systems for production of row crops (Landers, 2001). No-tillage system involves minimization of mechanical seedbed preparation and promotes reliance on herbicides and cover crops to kill or suppress weed growth. Seeding is done on an undisturbed or minimally disturbed soil allowing residue mulch to accumulate on the ground.

Applicability of no-tillage system however, is limited to certain soil types, crops, and ecological regions. The general criteria requires that (1) regions be characterised by high intensity rainfall at the beginning of the rainy season following a dry period, (2) regions should have two or three periods of seven to ten rainless days during the rainy season, and (3) total rainfall should exceed 500 mm (Thomas et al., 1984). **Table 1** shows that the Pandamatenga region satisfies these criteria, and thus no-tillage system could appropriately be practiced in the area. In addition to the above criteria, successful crop establishment with a no-tillage system also depends on the antecedent soil conditions and the land use history.

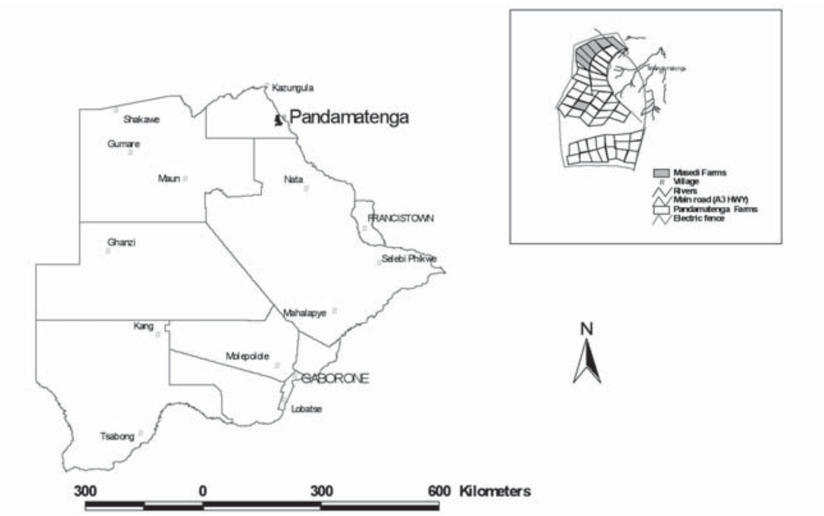
Although Pandamatenga vertisols have a high crop production potential, their development is constrained by the requirement for special management practices. Furthermore, the scantly available information in Botswana on vertisol management limits the successful application of no-tillage for agricultural production. The Debswana Mining Company's farming project, namely, Masedi Farms (Pty.) Ltd was started in 1998 to demonstrate the viability of no-tillage for the production of sorghum and cotton under rain-fed farming conditions in the Pandamatenga region (Botswana Gazette, 2002a). Masedi Farms Ltd operates on seven farms with a total area of 3,500 ha (**Fig. 1**).

Masedi Farms Ltd have for two successive years (2000-2001) produced 5 t/ha of sorghum from its farms (BOPA, 2002). Previously, farmers practising conventional tillage in the area had managed only about 0.3 t/ha of sorghum. As a result, some farmers/outgrowers in Pandamatenga have joined Masedi Farms Ltd in practising the no-tillage technology (Botswana Gazette, 2002b) and are also getting increased yield.

With these recent developments in Pandamatenga, the need for no-tillage research cannot be over-emphasized. Long-term and large-scale studies are necessary to generate data on yield levels, nutrient requirements, use of agrochemicals and equipment. The environmental effects of long-term use of herbicides under no-tillage system need to be investigated in order to understand the fate of agrochemicals and minimize the dependence on herbicides as the preferred mode of weed control. Minimizing energy-related inputs of tillage, fertilizers, and monitoring changes in the physical, chemical and biological status of the soil are other major areas that deserve a high attention.

The objective of this paper is to assess the status and potential of no-tillage agriculture in the Pandamatenga area using farmer experiences and available literature.

Fig. 1 Map of Botsuwana showing the location of Pandamatenga farms. Map on the insert is the expanded view of the farms



Methodology

The researchers visited the Pandamatenga area to familiarize themselves with the farming activities. During the visit, meetings were held with the head of agricultural research station and the farm manager at Masedi Farms Ltd. Field tours were made to verify the soil characteristics described in the literature as well as by the farmers. Literature was also reviewed regarding management and crop performance under no-tillage in areas with conditions similar to those in Pandamatenga. Assessment for the potential of no-tillage was based on apparent improvement in soil conditions achieved to date, and as described in the literature.

Soil Quality Status

Soil quality is defined as the capacity of a soil to function within a natural or managed ecosystem boundaries, to sustain plant and animal productivity, to maintain or enhance water and air quality, and to support human health and habitation (Soil Science Society of America, 1995; Doran and Parkin, 1994). Soil quality can be determined by evaluating soil properties that are subject to change as a result of the tillage practice imposed on them. These include the physical, chemical and biological characteristics of the soil.

Physical Properties

Pandamatenga vertisols exhibit characteristics that are typical to similar soils found in other parts of the world. These include formation of cracks down to 50 cm level and that are at least 5 cm wide. The soils occur on a lacusterine plain and are mostly imperfectly drained. When dry, they have a very hard consistence, but are plastic and sticky when wet. Hence, they are friable only over a narrow moisture range. Bulk density for Pandamatenga vertisols ranges from 1,300 kg/m^3 in the untilled topsoil to 1,370 kg/m^3 in the subsoil (Moganane et al., 1990).

Studies that demonstrate the effects of the no-tillage system on soil physical properties appear to be nonexistent in Botswana. However, most studies from other parts of the world show general improvement of the soil quality under no-tillage, while a few others (Kersten and Hack, 1991) have shown contradictory results. Gill and Aulakh (1990) reported that the no-tillage treatment gave the highest wheat yield and lowest bulk density on Zambian oxisols under rain-fed conditions when compared to conventional tillage. Other findings that contradict this result indicate that suitability of no-tillage is dependent on both the soil type and the crop being planted.

Dalal (1989) compared the effects of long-term conventional tillage with no-tillage on vertisols. He found that the aggregation index of the surface soil (0-10 cm) was higher under no-tillage. This is indicative of improvement in soil quality because of no-tillage practice. Aggregation is caused by the presence of organic matter in no-tillage system. The decomposing plant material releases organic colloids that act as bonding agents of the soil particles (Brady, 1984). A well-aggregated soil has a better pore system, making it easy for air, water, and nutrients to flow through the soil matrix.

In Australia, Marley and Littler (1990) compared several reduced tillage practices, including no-tillage, on the production of wheat grown on cracking clays. They found that the no-tillage, which retained stubble, gave the highest water storage efficiency. Holland and Felton (1989) reported similar results in a study investigating the response of grain sorghum to no-tillage. Water storage under no-tillage is aided by the increased retention of crop residue and organic matter. Crop residue acts as a mulch that reduces soil temperature and hence evaporation. Water also infiltrates better through the crop residue than on bare ground (Chan and Heenan, 1996). Organic matter stabilises the soil structure leading to high soil porosity and increased water infiltration.

The Pandamatenga soils have a poor structure that is not well drained. Initial infiltration rates on naturally occurring soils average 22.7 cm/hr while the final infiltration rates average 0.3 cm/hr. An increase in organic matter content will aid in retaining soil moisture, improve soil porosity and support aggregation of the soil particles.

Chemical Properties

Soil chemical properties include the cation exchange capacity (CEC), soil reaction (pH), exchangeable cations, organic matter, and macro and micro-nutrients. Organic carbon, which is used for estimating organic matter, is relatively low in most soils of Botswana due to high soil temperatures that promote organic matter decomposition. Further, there is also little accumulation of plant residue because of low rainfall and frequent drought. By comparison, Pandamatenga vertisols have better chemical properties for crop production than other soils in Botswana. Consequently, the use of fertilizers by the farmers is still low. However, available phosphorous and nitrogen are low in Pandamatenga vertisols, and as such the soils will respond to addition of nitrogen and phosphorus fertilisers by producing more yield.

No-tillage influences chemical properties of soils positively. Dalal et al. (1991) measured organic carbon, total nitrogen, pH and microbial biomass in a vertisol in Australia after twenty years of no-tillage. The organic carbon, total nitrogen and microbial biomass levels were found to have increased significantly in the top 25 cm of the soil. A strong stratification with depth was also found with all the soil properties, suggesting that no-tillage and residue retention promoted stratification of the chemicals.

The fibre content of the soil is reported to have increased on the Masedi Farms Ltd since the commencement of no-tillage farming in 1998. This is in agreement with findings of Zibilske et al. (2002) and Saffigna et al. (1991) who found that organic matter of the surface soil increased under no-tillage. Other nutrients, specifically zinc and manganese, are also reported to have reached optimum levels at Masedi Farms Ltd, such that they do not need to be added.

Soil Life

Living organisms in the soil consist of micro-organisms such as bacteria, fungi, algae, protozoa, nematodes, insects, and earthworms. The breakdown of organic matter to release nutrients to plants largely depends on these organisms. Where there is no addition of fertilizer, plants rely on organic matter as their source of nutrients. In undisturbed soils, most of

Table 1 Five-years (1997-2002) rainfall amounts (mm) for the Pandamatenga farms

Year	Month									
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
1997/98	17.8 (2)	25.8 (6)	60.4 (5)	68.9 (6)	143.5 (12)	68.1 (6)	82.5 (2)	6.5 (1)	-	473.5 (42)
1998/99	-	7.6 (1)	152.9 (6)	96.7 (8)	72.2 (8)	54.2 (3)	-	-	-	429.8 (26)
1999/00	-	5.2 (1)	45.8 (5)	119.1 (10)	181.1 (12)	287.8 (8)	64.2 (5)	-	-	703.2 (42)
2000/01	3.5 (1)	23.0 (1)	89.4 (8)	102.9 (13)	25.5 (2)	192.6 (11)	185.7 (6)	21.7 (2)	-	644.3 (44)
2001/02	-	37.7 (4)	87.2 (8)	101.9 (10)	151.0 (8)	44.7 (5)	29.2 (2)	46.2 (2)	-	497.9 (39)

Note: Figures in brackets indicated total number of rainy days
Source: Padamatenga Agriculture Research Station

the nutrient cycling, roots, and most biological activities are found in the top 20 to 30 cm, known as the rhizosphere. In the rhizosphere, the plant, soil and soil micro-organisms are symbiotic. Plants provide the carbon and food source for soil organisms that bind the soil particles into aggregates and recycle soil nutrients. Soil provides the habitat, water and mineral nutrients for both soil organisms and plants. Management techniques that change the amount and quality of carbon going into the soil as either residue or root exudates will effect change in the soil biology.

Brady (1984) defined soil management as the sum of all tillage operations, cropping practices, fertilizer, soil amendments, and other treatments applied to the soil for the production of plants. This definition puts emphasis on the link between all farming practices and the soil. Tillage directly affects soil porosity and the placement of residues. Porosity determines the amount of air and water the soil can hold. Residues affect the soil surface temperature, rate of evaporation and water content as well as nutrient loading and their rate of decay. This leads to more soil life and hence higher nutrient loading capacities and a more continuous release of nutrients.

Hughes and Herridge (1989) found that plant growth, seed yield, and nodulation index of soybean increased under no-tillage. Nitrogen fixation was also found to be higher in the no-tillage plots. Under no-tillage system, the organic matter decomposes more slowly. This occurs because the low nitrogen content of crop residues, especially cereal crops slows the feeding of micro-organisms (Grant and Bailey, 1994).

Earthworm numbers increase dramatically under no-tillage system. In a long-term dryland tillage experiment, Clapperton et al. (1997) found as many as 300 earthworms per square metre under no-tillage system compared with none under conventional tillage. In the same experiment, there was significantly lower incidence of common root rot under no-tillage compared with conventional tillage, demonstrating the long-term benefit of maintaining the soil habitat. Masedi Farms Ltd observed an increase in earthworm population over a period of 4 years. Earthworms are usually a sign of good soil quality since they improve the physical properties of soils.

Managerial Aspects of No-Tillage

The Pandamatenga vertisols exhibit two important characteristics that dictate the management system that can be successfully used to produce crops. The soils are soft and plastic when wet, and very hard and with deep cracks when dry (Arup-Atkins, 1990a). In addition, the area receives relatively high rainfall averaging 600 mm and making it difficult to access the fields immediately following rainfall. These two factors result in high draught requirement, high erodibility of the soil, large strong clods in the dry seedbed, and a narrow range of optimum water content for tillage (Arup-Atkins, 1990b).

Crop Production

Management of vertisols for crop production varies regionally depending on whether they occur in the humid tropics, or in temperate areas. Problems that are generally experienced in one area may be of little consequence in the other. For example, the large clods formed by tillage in the tropics are usually disintegrated by the freezing and thawing phenomenon in the temperate region and so there is little need for follow-up tillage unless it is done for weed control. On the other hand, in the tropics, secondary tillage is required to break down the clods since there is no freeze-thaw effect. In addition, vertisols in the sub-humid tropics as in the Pandamatenga, tend to have specific requirements for water management (Ahmad and Mermut, 1988) to remove excess water following rainfall.

Sorghum was tried under commercial production in the Pandamatenga region in the early 1950s. Since then, the yields have been as low as 0.3 t/ha. Arup-Atkins, (1990c) reported a low sorghum suitability rating for the area while the suitability for maize was very marginal. The main constraint to improved yields was identified as slow soil drainage and poor workability of the soil. Some farmers employed tillage methods similar to the ones they previously used in arenosols that are common in most of the country where arable production is practiced. However, more recently, Masedi Farms Ltd was able to obtain yield levels of up to 5 t/ha and 2.8 t/ha for sorghum and cotton respectively (BOPA, 2002). The high yield is also evident in other crops such as sunflower and cotton grown by Masedi Farms Ltd. The success of Masedi Farms Ltd is attributed to the use of fertilizers and adoption of no-tillage system as opposed to conventional tillage system that was used by previous farmers, who also applied less fertilizer.

Mechanization

Under conventional tillage system, tillage equipment is used primarily to prepare the seedbed, control weeds, and incorporate fertilizer and manure (Tapela and Colvin, 2002). The narrow range of optimum water content for tillage and the clotting nature of vertisols present difficulties in adopting conventional tillage practices. Clods make it necessary to follow primary tillage operations with a cultivator to level the seedbed. As a result, more field operations are required and there is increased energy requirement. However, under no-tillage, the seedbed is maintained rather than being rebuilt every year. It is therefore not necessary to plough the soil every year. Specialized equipment such as air seeders are used to plant the crops with minimal disturbance of the soil. Only a narrow strip of about 5 cm along the planting area is disturbed. Practising controlled traffic, where the same travel paths are maintained for all field machinery in all years, also minimizes compaction. The reduced need for tillage operations saves on fuel and labour requirements. During the wet season (October to April) in Pandamatenga, some months may have only 8 days when fieldwork may be done effectively as the fields become inaccessible due to water logged soils. There is thus a narrow window (November 15 to December 15) when grain crops may be planted. Therefore, no-tillage provides an alternative that can be used to ensure timely execution of field operations. Additional equipment required under no-tillage system include various chemical application equipment for spraying herbicides, pesticides, and fertilizers.

Chemical Use

The use of herbicides and pesticides by the Pandamatenga farmers is on the increase. The types of chemicals used also vary as shown in **Table 2**. However, the use of herbicides (Atrazine, Glyphosate and 2,4-D-Amine) to control weeds on vertisols can be hazardous because of the high initial infiltration rate through the cracks resulting in contamination of underground water.

The almost zero infiltration when the soil is wet can also contaminate ground surface water bodies. This is especially true if the farmer is not experienced such as those in the Pandamatenga Outgrowers Association (Botswana Gazette, 2002b). These are small farmers who emulate methods used by Masedi Farms Ltd, and most are without the necessary training to manage herbicides. It is difficult to manage modern farming without the assistance of consultants, especially with regard to soil management. In that regard Masedi Farms Ltd conducts soil tests every season to determine the level of soil nutrients and make management decisions concerning fertilizer requirement.

Conclusions

No-tillage system has only been practised in Botswana on a large scale since 1998 by Masedi Farms Ltd. Therefore, research literature on the subject is scanty. Available literature on the performance of no-tillage is from other countries that have similar soils and climatic conditions. Based on this literature and farmer experience in the Pandamatenga area, it is evident that no-tillage system has a potential to replace conventional tillage system. The increased yield returns obtained by Masedi Farms Ltd is attributable to a combination of no-tillage system and increased use of fertilizer. However, the effect of each factor needs to be isolated so that no-tillage can be assessed adequately. In spite of that, the success of Masedi Farms Ltd has led to the adoption of no-tillage by the Pandamatenga Outgrowers Association. Positive results associated with no-tillage system include, improved soil organic matter content, increased soil biological activity, higher nutrient level, lower bulk density, and increased water infiltration rates. The positive change is noticeable only after four years of practicing no-tillage. The long-term implications of adopting no-tillage are unknown at the present moment.

No-tillage system relies on heavy use of agricultural chemicals, which may impact negatively on the environment if not well managed. The economic benefits also take time to be achieved as the high cost of specialized machinery take a long time to be offset. As a result, only long-term research that can monitor no-tillage farming will answer concerns about the long-term implications of no-tillage in the Pandamatenga area. It is therefore recommended that further and more intense studies be carried out to evaluate the environmental and economic implications of adopting no-tillage system.

Acknowledgements

The authors would like to thank Mr. C. Bullen of the Pandamatenga Agricultural Research Station and Mr I. Keane of Masedi Farms Ltd for their insight about no-tillage farming in the Pandamatenga area. We thank also Mr. J. N. Aliwa for his valuable contribution in reviewing the manuscript. Gratitude also goes to Botswana College of Agriculture who provided financial support to visit Pandamatenga area.

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Table 2 Types of pestcides and herbicides used by Pandamatenga farmers

Crop	Pestcide	Herbicide
Sorghum	Endoflo	Lasso (alachlor)
	Supermatrine	Roundup (glyphosate)
	Mospilan	2,4-D Amine
	Cypermethrin	MCPA
	Thionex	Atrazine
	Metasistox	
	Demeton	
	Sulmethine	
	Phonex	
Sunflower	Parathion	

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