A Comparative Assessment of Soil Fertility on Flood Recession (Molapo) and Dryland Farms: The Case of Xhobe Settlement in the Okavango Delta World Heritage Site

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Abstract

Soil fertility assessment is a crucial step in determining the productivity of farms in a specific locality. In this paper total nitrogen, phosphorus, soil organic matter and pH are compared in two arable farming systems namely flood recession and dryland farms. The objective of the research is to assess nutrient dynamics in soils of the two farming systems. Farms were randomly selected and stratified sampling technique was used to collect soil samples on flood recession and dryland farms. The collected soils were analysed for the afore mentioned parameters. The results indicate that nutrient pools increase with upturn in moisture and more alkaline soil conditions. Nitrogen and soil organic matter contents are higher in soils from the flood recession farms while phosphorus was not detected at all. Soils in the flood recession farms are more basic over dryland ones with the former having an average pH of more than 7 and the latter less than 7. A pH value below 7 indicates the soil is acidic, while values above 7 are alkaline or basic. There is higher organic matter accumulation in flood recession farms, which is associated with high decomposition rate that lead to the release of nitrogen into the soil. Therefore, with respect to soil organic matter and nitrogen contents, flood recession farms are more fertile than dryland farms, whereas with regard to phosphorus there is a limited supply in both farming practices. In conclusion, an external input of phosphorus or organic fertilizer is needed to improve the productivity of farms in Xhobe settlement and the rest of farms located in the Okavango Delta Ramsar site so that farmers can have increased yield and meet their household food security needs.

Introduction

Soil fertility is fundamental in determining the productivity of all farming systems (Watson *et al* 2002). The productivity of soil is largely determined by its fertility, which in turn is dependent on the root development zone depth and nutrients stored in its mineral and organic constituents (Vlek *et al* 1979). Growth and yields of a crop are a result of the interactive response of the plant to weather and soil factors (Spiertz and de Vos 1983). That response may be modified by the occurrence of pests, diseases and weeds. Assuming optimum crop protection, crop growth is governed by environmental conditions and availability of water and nutrients (Spiertz and de Vos 1983), which are mostly found in soil organic matter (Weinhold and Halvorson 1998). The soil organic matter (SOM) is the organic fraction of soil consisting of plant and animal residues at various stages of decomposition and the synthesized by-product of soil organisms. SOM influences cation exchange capacity (CEC), aggregate stability and energy supply central to the release and availability of nutrients for primary production and therefore a key indicator of soil quality(Brady and Weil 2000).

Farmers in and around the Okavango Delta practice two arable farming methods namely, dryland and floodplain arable farming (Magole and Thapelo 2005). Dryland farms depend mainly on rainfall while floodplain farms are in or along a river channel. Diverse types of crops are grown such as maize, millet, sorghum and pumpkins. Diversification of crops alters the pattern and degree

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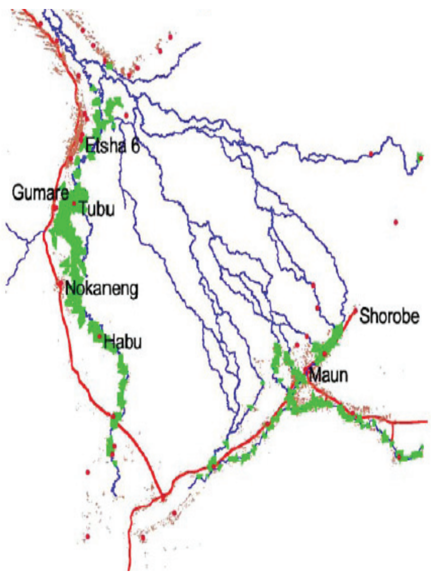
of nutrient removal and influences microbial activity and soil quality (Grant *et al* 2002). Although cropping intensification and diversification influence most plants, Nitrogen (N) and Phosphorus (P) are the most commonly deficient for crop production and are the most likely to be affected by management practices (Grant *et al* 2002).

Sustainability of cropping systems requires nutrients from the soil balanced by nutrient replacement so that soils are not depleted of their fertility. Effective nutrient management requires that nutrient availability be matched to crop demand (Welty *et al* 1980). Increasing crop production increases the amount of plant biomass produced and returned to the soil as surface residue or root material. This has the potential to increase soil organic matter content (Wood *et al* 1990). Changes in soil quality attributes can influence crop yield potential and the amount and distribution of roots in the soil (Campbell and Zenter 1993).

A land assessment on the basis of satellite images compiled by Vanderpost (2009) found that of 48,900 hectares cleared for cultivation in and around the Okavango Delta area, 75% consists of dryland arable farms while 25% consists of farms temporarily in floodplains or flood recession farms. The research further indicates that crops mature earlier and yields are higher in the floodplain farming system (Figure 1) because of moisture availability due to periodic flooding and more fertile soils. For example, dryland and flood recession farmers harvested 121kg per hectare and 500kg of sorghum per hectare, respectively in 2009 (Vanderpost 2009). However, the assessment does not show how soil nutrient content, organic matter, and pH differ between the two farming practices even though it is proven that these are the most essential nutritional elements for plant growth. Therefore, an in-depth understanding of the dynamics of soil nutrients on these two farming systems is essential for appropriate guidance of farmers engaged in the farming practices in order to attain food security in the area. Therefore, this research addresses this gap.

Figure1: Flood recession farms (shown in green) in the Okavango Delta World Heritage Site



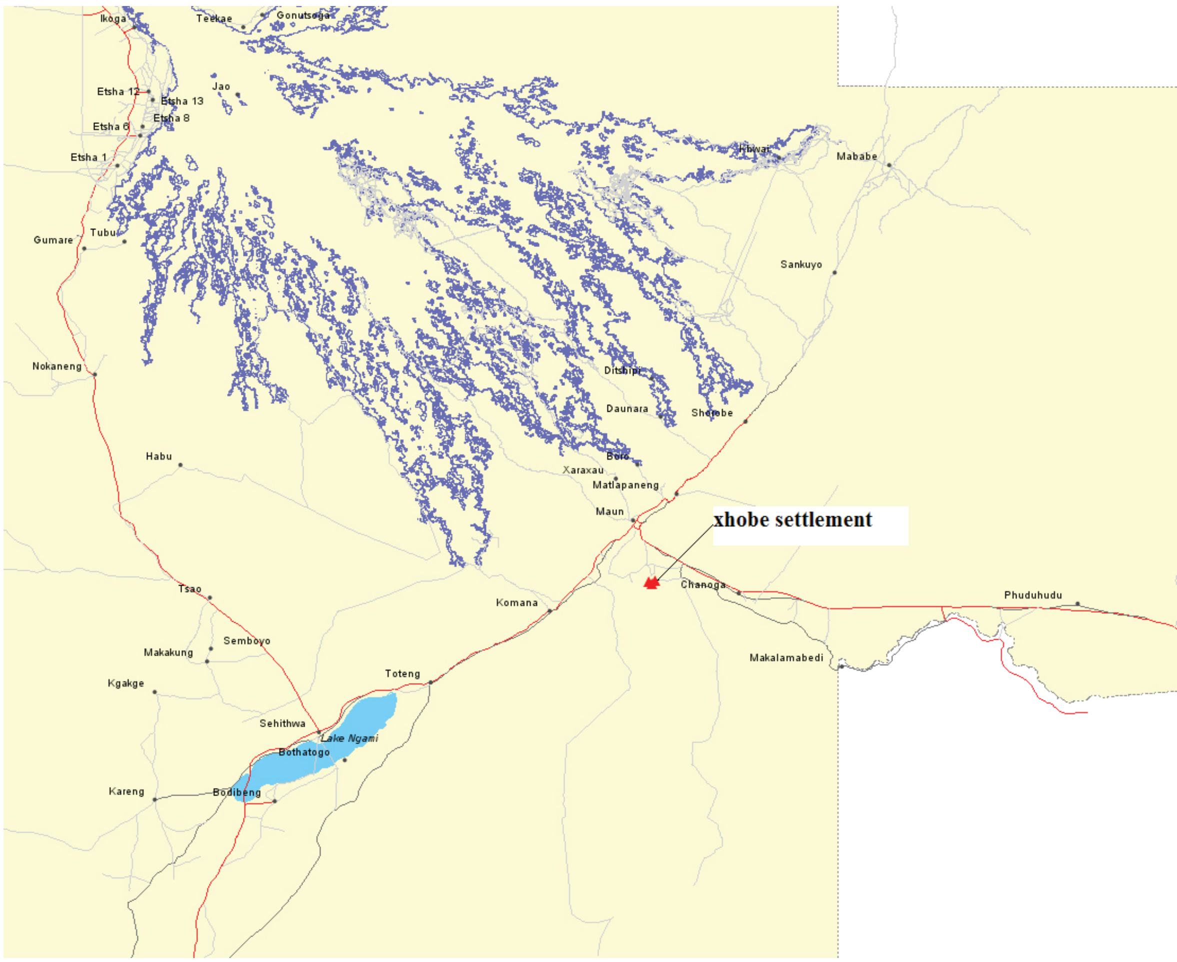
Source: Vanderpost (2009)

Materials and Methods

Study Area

Xhobe settlement is about 35km from Maun in the south eastern fringes of the Okavango Delta Ramsar site in Botswana (Figure 2). It is S20° 13′ 40″-S19° 56′ and E23° 46′-E23° 45′ (UNDP/FAO 1986). The area is dominated by trees and shrub savanna. Its climate is described as semi-arid with very high summer temperatures and a pronounced winter season (Masundire *et al* 1998).The rainfall that occurs between the months of October and March is variable and ranges from 480mm to 560mm (Republic of Botswana 1989). Soils in this area originate from alluvial deposits (McCarthy *et al* 1998) and form part of the Kalahari sand geologic formation (Grove 1969).

Figure 2: Location of Xhobe settlement in the Okavango Delta Ramsar Site



Source: prepared by authors

Soil Survey

Simple random sampling was used to select the farms where soil samples were collected in flood recession and dryland farms. Stratified random sampling design was used for soil sample collection with the highest number of samples collected from the largest farm. Sixty composite soil samples were collected and analysed consisting of two sets of thirty samples each from flood recession farms and dryland farms. All samples were collected at a 20cm depth using an auger, then placed inside plastic bags and taken to the laboratory for chemical analysis.

pH Analysis

An amount of 20g of wet soil from each sample was weighed into a 50ml container, and 40ml of ultra pure water added to make a solution. Samples were shaken for 20 minutes in a Labcon SP081UPFSS digital oscillator and left for 10 minutes to stand then pH was taken using a WTW 330i pH meter. This was repeated for all collected samples from both floodplain and dryland farms.

Soil organic matter analysis

Soil organic matter was determined by loss on ignition at 450°C. Soil samples were oven dried at 105°C for 24 hours and cooled in a desiccator. A mass of 2g of the soil from each sample was weighed into the crucible and oven dried at 105°C for three hours, then cooled and weighed. This weight was taken to be the initial weight. The oven dried sample was heated again at 450°C for two hours and weighed after cooling. The sample was heated again at 105°C for three hours until the mass remained constant. The constant weight was considered the final weight. To get the amount of organic matter in such a sample, the final weight was subtracted from the initial weight. The difference was considered to be total organic matter that was present in that sample. This was done for each sample from both floodplain farms and dryland farms. Percentage organic matter was calculated as:

$$\mathrm{SOM} = \frac{[(W105 - W450)]}{W105} \; X \;\; 100$$

Nitrogen and phosphorus analysis

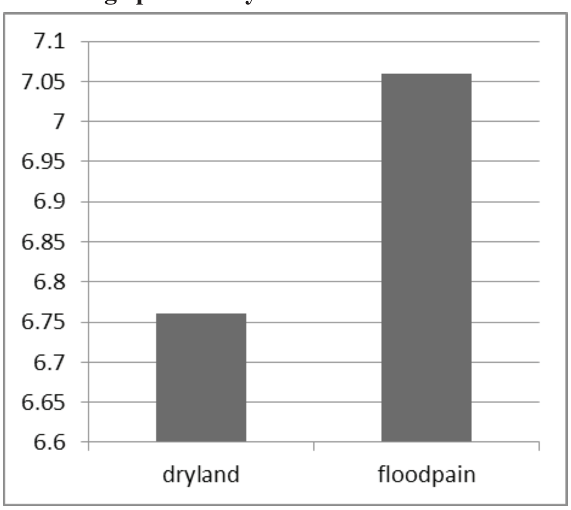
Nitrogen and phosphorus were detected using Sulphuric acid digestion method in a continuous flow analyzer machine (AA3). One selenium tablet, 2g of Potassium sulphate, 2g of wet soil sample were digested with 6ml of Sulphuric acid using a 100ml digestion tube in a block digester for one hour at 450°C. Then the concentrated solution was brought to the mark with distilled water and digests loaded in an AA3 machine.

Results

Soil pH, soil organic matter, nitrogen and phosphorus analysis

Soils from flood recession farms are neutral to alkaline compared to soils from dryland farms that are slightly acidic, with an average pH of 6.76 and 7.06 in the dryland and flood recession fields respectively (Figure 3).

Figure 3: Average pH for dryland and flood recession farms



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The results also show that soil organic matter (SOM) is higher in flood recession farms with an average of 0.2g/kg compared to dryland farms soils that have an average of 0.09g/kg as indicated in Figure 4.

Figure 4: Average SOM (g/kg) for dryland and flood recession farms

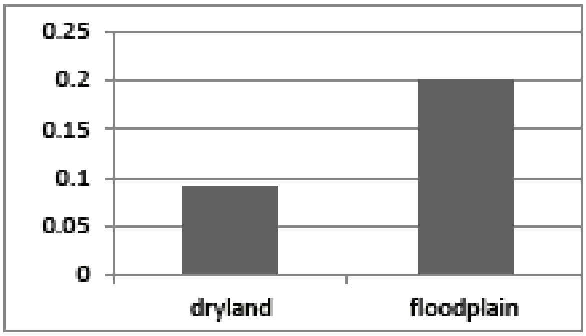

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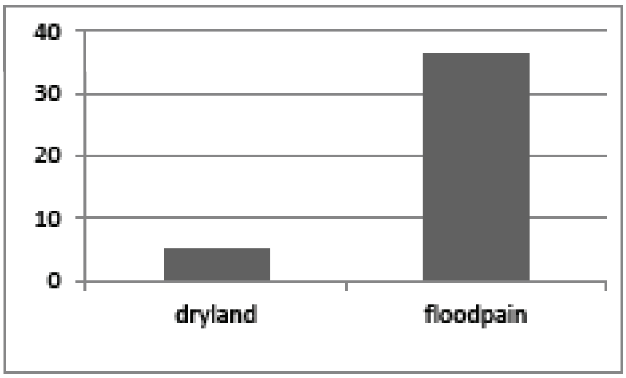
Figure 5 below clearly reveals that flood recession farms have higher nitrogen content compared to dryland ones. The average total nitrogen content for dryland farms is 4.99mg/kg and that for flood recession farms is 36.50mg/kg.

Figure 5: Average total N(mg/kg) for dryland and flood recession farms



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Statistical Analysis

Soil pH

An independent t-test from the statistical package for social sciences (SPSS) was used to test if there is any significant difference in soil pH from flood recession and dryland farming systems. The derived P was 0.03 at a significance level of 0.05. Therefore, the null hypothesis that there is no significant difference in pH from the soils in the two arable farming systems is rejected. That is, soils in dryland farms differ in pH from soils in floodplain farms.

Soil organic matter (SOM)

The same method used to compare pH for soils in the two farming systems was used to test if there is a significant difference in SOM contents from flood recession and dryland farms at a significant level of 0.05. The resultant P was 0.04, which is <0.05. Therefore, the null hypothesis that there is no significant difference in the organic matter content between the two arable farming systems is rejected. Thus the results show that the amounts of organic matter contents in the two types of arable farms differ.

Nitrogen

Total N in both flood recession and dryland farms were compared using an independent t-test to determine if they are significantly different from each other at 0.05 significance level. The resultant P was 0.04, which is also <0.05 showing that there is a significant difference in the nitrogen content from the two arable farming systems.

Discussion

Importance of soil pH

Soil pH is a measure of the soil acidity or soil alkalinity. It is an important consideration for farmers and gardeners because many plants and soil life forms prefer either acidic or alkaline conditions, and some diseases tend to thrive when the soil is alkaline or acidic. The pH can affect the availability of nutrients in the soil (Curtin and Wang 1999). It is shown from the results that flood recession soils (average pH = 7.06) are more basic than dryland (average pH = 6.76) soils. The pH of soil or more precisely the pH of the soil solution is very important because soil solution carries in it nutrients such as N, K, and P that plants need in specific amounts to grow, thrive, and fight off diseases (Ziadi *et al* 1999). If the pH of the soil solution is increased above 5.5, N (in the form of nitrate) is made available to plants (Vinten *et al* 2002). The pH of the soils from the two arable farming systems are above 5.5, thus the availability of moisture either from rainfall in the case of dryland farming or river flow on floodplain farms should support the release of plant available N from the soils.

Certain bacteria help plants to obtain N by converting atmospheric N into a form of N that plants can use. These bacteria live in root nodules of legumes and function best when the plant they live in is growing in soil within an acceptable pH range of 6.3–7.6 (Davidson *et al* 1990). If the soil solution is too acidic plants cannot utilize N, P, K and other nutrients they need. In acidic soils, plants are more likely to take up toxic metals and some plants eventually die of toxicity or poisoning. The results from this study show that both dryland soils and floodplain soils fall within the acceptable pH range to allow for bacterial conversion of atmospheric N into a form that plants can use. However, bacteria in soils are found in the organic matter, thus the presence of less organic matter in dryland farms implies that there are relatively less numbers of bacteria there as compared to flood recession farms and consequently small amounts of atmospheric N conversion.

The majority of food crops prefer a neutral (pH 7) or slightly acidic soil. Some plants however prefer either more acidic or alkaline conditions. A pH level of around 6.3-6.8 is also the optimum range preferred by most soil bacteria although fungi, molds, and anaerobic bacteria have broader tolerances and tend to multiply at lower pH values. Therefore, more acidic soils tend to be susceptible to souring, rather than undergoing the sweet decay processes associated with the decay of organic matter, which immeasurably benefit the soil. The near-neutral conditions such as those found in the soils of our study area are hospitable for production of food crops. Installation of irrigation systems and the use of fertilizers could improve the productivity of the soils in the dryland fields and widen the crop range in the area. This is a potential area for increased dry-season or winter production of high value crops such as vegetables that could benefit farmers in the region while at the same time helping towards attaining food security, and preventing malnutrition in a country that is prone to diseases such as HIV/AIDS.

Soil organic matter

Organic matter is the material that is capable of decay, or the product of decay (humus), or both (Vinten *et al* 2002). Usually the organic matter is the remains of recently living organisms, and may also include still-living organisms. Results from this research show that soils from floodplains have higher organic matter contents over dryland soils with an average of 0.2g/kg and 0.09g/kg of soil, respectively. There are many reasons why floodplain soils are richer in organic matter. One of the reasons is higher decomposition rates in the floodplains leading to accumulation of organic matter. Decomposition is a biological process that includes the physical breakdown and biochemical transformation of complex organic molecules of dead material into simpler organic and inorganic molecules (Juma 1998). Floodplain farmers leave the plant residues after harvesting as shown by Figure 6 below and since soil organic matter is derived mainly from plant residues, this allows higher accumulation of organic matter in these fields.

Source: photographed by authors

Accumulated organic matter, therefore, is a 'storehouse' of plant nutrients. As a result, higher yields are produced because upon decomposition the nutrients are released as plant-available form. The stable organic fraction (humus) absorbs and holds nutrients as plant available form. This in turn allows for early maturity and higher yields in floodplains fields as indicated by the study compiled by Vanderpost (2009).

As organic matter slowly decomposes, it colours the soil darker, increases soil aggregation and aggregate stability, and increases the cation exchange capacity (Yeates *et al* 1997). Therefore, because floodplain soils have higher amounts of organic matter they have a better ability of attracting nutrients and retaining stability. Organic matter increases the nutrient holding capacity of soils and it is a pool of nutrients for plants because it binds nutrients preventing them from becoming permanently unavailable to plants. It is also a food for soil organisms ranging from bacteria to worms, which also hold on to nutrients and release them in forms available to plants (Yeates *et al* 1997). Because of all these, soils from the floodplain fields are considered more fertile as indicated by organic matter content. Sediments deposited by the river during high flows increases the rate of accumulation of organic matter and fertility in floodplain soils (Duvail and Hamerlynck 2007). In the dryland fields organic materials are translocated or leached into deeper layers of the soil after heavy rainstorms characteristic of sub-tropical areas resulting in less accumulation of organic matter on the surface (Figure 7).

Source: photographed by authors

Nitrogen

Cooke (1967) asserts that soil fertility is the capacity of soil to produce the desired crops. According to this concept, soil nitrogen fertility can be defined as the ability of soil to control the flow of nitrogen in a soil-plant system for the production of the crops desired. Although nitrogen is the most abundant element in the atmosphere, plants cannot use it until it is naturally processed in the soil, or added as fertilizer. From this study flood recession fields soils are richer in nitrogen compared to dryland farms soils with the former having an average of 36.50mg/kg of soil and the latter 4.99mg/kg of soil. This large difference is associated to high organic matter content and the availability of moisture in the floodplains. Soil moisture influences microbial activity, which activates the release of N from soil organic pool. Nitrogen cycling processes tend to increase in wet soils and decline in dry soils (Yeates *et al* 1997).

Therefore, because of the dry status of soils in the dryland farms, decomposition process that can result in the release of nitrogen is very limited. As a result of this there is limited total nitrogen in dryland farm soils while there is enough total nitrogen in the floodplain farm soils. Nitrogen in the flood recession fields is considered enough for plant production as the UNDP/FAO (1986) indicates that normal nitrogen in the soil ranges from 30mg/kg-40mg/kg of soil. Although most agricultural soils contain several thousand kilograms of N per ha in organic forms, a large proportion of the total soil N remains physically and chemically protected from microbial degradation in the form of stable soil organic matter, and thus is unavailable for plant uptake (Jenkinson *et al* 1987). Even though there is a high number of total N in flood recession farms some of it may be protected from microbial degradation in the form of stable soil organic matter. However, the high crop yields associated with flood recession farms suggest that the amount of plant available N is sufficient for plant production in the area.

Observed high accumulation of clay in floodplains also contributes to higher contents of nitrogen in floodplain soils because clay binds with humus, chemical substances, and fine mineral particles, while in the dryland there is no such accumulation. It is proven that nitrogen accumulation in soils is favoured by high clay content, which attracts fine mineral particles to maintain fertility (Ziadi *et al* 1999). Therefore, as it is found from this study, floodplains have higher contents of N while dryland soils have lower N. Also, prior to clearance for agricultural activities, floodplains are dominated by grassland while dryland soils are mostly dominated by trees and shrubs. Some grasses have nodules which are capable of converting atmospheric N into nitrates that are ready for plant use

(Yeates *et al* 1997). This is probable in the study area as indicated by higher amounts of total N from floodplain field soils as compared to dryland ones.

Transportation or translocation of organic materials also leads to a decrease in N contents because N is directly linked to availability of organic matter (Breland and Hansen 1996). It was observed that leaching occurs in the dryland farms, which leads to less accumulation of organic matter hence less N contents. Farmers in both regimes allow free access for animal grazing after harvesting but more animals concentrate in the floodplains because of availability of water for drinking. Animal manure is an important source of N in the environment. The quantity of N in the manure depends on the animal species, their age and diet (Wardle and Lavelle 1997). The researchers observed a higher population of cattle in the floodplains. Most animals transfer N from the dryland arable farms to floodplains as they are attracted by water in the river and drop their waste on floodplain farms.

Conclusion

We have observed that the specific fertility constraints of dryland soils are low organic matter and total nitrogen contents. Observed soil physical constraints include coarse texture, excessive infiltration rate and frequent water stress. The flood recession farms have higher fertility status and hospitable physical conditions as indicated by organic matter, nitrogen and pH contents. The improvement in physical properties of flood recession farms is attributed to observed increased clay and silt content of floodplain soils. However, flood recession farms are susceptible to seasonal flooding, which could drastically affect cropping if adequate management measures are not adopted. Installation of irrigation systems and the use of fertilizers could improve productivity of soils in dryland farms and widen the crop range there. This is a potential area for increased dry-season or winter production of high value crops such as vegetables, which requires low-external fertilizer input strategies especially based on organic materials.

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