

Assessing the Available Macro and Micronutrients in Soils from Magwi County, Eastern Equatoria, South Sudan

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Abstract- The growth of plants is a result of both macronutrients and micronutrients, which are equally important and play different vital roles. This study was designed to assess the soil characteristic, macro and micronutrients that are available in farmer field sites in Magwi County, South Sudan, which aids in understanding the future growth potential of crops. Soil samples collected from different locations in Magwi County were analyzed for soil characteristics, macronutrients, including nitrogen, phosphorous, potassium, calcium, and magnesium. Additionally, micronutrients like zinc, iron, copper, and manganese were examined. The availability of nitrogen was found to be low in almost all soil samples, while phosphorus was found to be low, medium, and high, while potassium was found to be high. All soil samples showed high levels of calcium and magnesium. The availability of micronutrients (iron, manganese, zinc, and copper) was found to be low to medium in almost all soil samples. The data reveals that in soils are deficient in macro and micronutrients which requires addition of extra fertilizer and manures to improve the overall fertility of the soil and make it suitable plantation and increase their healthy growth.

Keywords: Soil Analysis, Macronutrients, Micronutrients, Magwi, South Sudan.

I. INTRODUCTION

Soil is a natural body which develops as a result of pedogenic processes which take place during and after weathering of parent rocks in which plants and other forms of life are able to grow. The soils of Sub-Saharan African countries have a low level of inherent fertility, which is associated with specific natural constraints for each Agroecological zone. South Sudan is ecologically divided into six agroecological zones namely: the Greenbelt, Ironstone Plateau, Hills and Mountains, Flood Plains,

the Nile/Sobat Rivers, and the arid and pastoral zone. The most important crops grow include maize, sorghum, millet, cassava, groundnuts, and beans. Smallholder farmers are the main drivers of South Sudanese agriculture sector. According to World Bank, smallholder farmers who are resource-poor, cultivate an average of 0.4-0.5 hectares, making up 83% of all farming households [1]. Agriculture refers to the art of growing plants from soil and is one of the most economical factors for human beings. Agriculture is largely influenced by controlling factors like climate and soil topography, while soil erosion is a serious problem for agricultural productivity. In order to achieve better crop yield, farmers should be made aware of the nutrients that are provided to the crop. With this kind of awareness, farmers will maintain proper yield and economics of production.

The status of nutrient levels in South Sudan is not well-known due to the lack of soil testing, which is unfortunate. Soil nutrient depletion problems in specific areas may be caused by various factors. Continuous cultivation on the same land with no crop residue incorporation and/or inadequate application of chemical fertilizer can greatly affect crop production. Continuous cultivation without addition of substantial amount of soil organic matter (SOM) will cause the sharp decrease in SOC and nitrogen [2].

For soil to sustainably perform its functions, understanding its potentials and limitations is crucial. Before intensive use, it is important to understand the physical, chemical, and biological properties of soil. It is necessary to use agrochemical fertilizers inputs under different crops to compensate for the lack of

nutrients [3]. The productivity of various crops is greatly influenced by soil fertility. It is also seen as part of the sustainable agricultural production process. The productivity of soil is dependent on its ability to supply nutrients to its plants. The lack of these essential nutrients can severely affect soil stability and productivity [4]. The nutrients and water retention required by crops are provided by fertile soil, which is rich in organic matter. It also has an equilibrated texture for easy water drainage [5]. By understanding the dynamics of nutrient uptake and their biological interactions, croplands can be more efficient. In this situation, understanding the chemical composition of the soil and its variations is essential for utilizing and managing the soils. In order to assess soil fertility, quality, and productivity, it is necessary to measure soil chemical levels like total nitrogen, total and available phosphorus, soil organic carbon, electrical conductivity, and pH [6]. Furthermore, soil chemical properties play an important role in assessment and advancement of sustainable ecosystem management [7]. Excess nitrogen and phosphorus may lead to agricultural non-point source pollution and water quality degradation [8]). Soils with high electrical conductivity values have the potential to impact soil aggregation and structure. Understanding and using the spatial variability of soil chemical properties can be useful in improving soil quality, increasing soil productivity and health, advancing agriculture, and protecting the environment. The concept of soil quality has been suggested by several authors [9]; [10] & [11], as a tool for assessing long-term sustainability of agricultural practices at local, regional, national, and international levels. Plant growth and development is governed by many important roles played by calcium (Ca²⁺), which is a divalent alkaline cation. When Ca²⁺ bioavailability is low, crop yield and quality can be suboptimal, depending on the species and environmental conditions. Calcium is abundant in neutral and alkaline soils. However, calcium deficiency is most common in highly weathered acid soils, such as Oxisols and Ultisols. Large areas of Oxisols and Ultisols are found in the tropics, covering about 43% of the tropics, including large areas in South America and central Africa [12]. The physicochemical properties such as soil texture, soil organic matter, calcium carbonate, cation exchange capacity, pH, and

electrical conductivity of soil play a significant role in determining nutrient availability. The present investigation was carried out to assess the soil characteristics, available macro and micronutrients in some farmer field site in Magwi county which help in understanding the future scope of growth of crops also help farmers with the exact quantity of fertilizers they need to supply for the adequate production of their crops and maintain their economy.

II. MATERIAL AND METHODS

Location

Magwi County is located in Eastern Equatorial State, with longitudes of 31.715° E and 32.887° E, and latitudes of 3.3.497° N and 4.395° N. Its elevation is between 514-2,223 meters above sea level. The county borders Imatong County to the east and Republic of Uganda to the southwest. Crops grown in the County include cassava, maize, and sorghum, with some cultivation of sweet potatoes, groundnuts, and beans [13].

The site of study includes a farmer's field in eight beams of Magwi count, namely Loa, Moli, Sau1, Parjok 1, Parjok 2, Parjok 3, Palwonganyi 1, and Palwonganyi 2.

The study area is located at farmer field sites in Eastern states, where selected biomass is shown in Table 2.1.

Table 2. 1. Displays the location of the sample's location

S/N	State	County	Payam Boma/ Site	Samples
1	Eastern Equatoria	Magwi	East Pageri Loa	
2	Eastern Equatoria	Magwi	East Pageri Moli	
3	Eastern Equatoria	Magwi West	MagwiSau 1	
4	Eastern Equatoria	Magwi West	MagwiParjok 1	
5	Eastern Equatoria	Magwi West	MagwiParjok 2	
6	Eastern Equatoria	Magwi West	MagwiParjok 3	
7	Eastern Equatoria	Magwi West	MagwiPalwonganyi 1	

8 Eastern Magwi MagwiPalwonganyi 2
Equatoria West

Climate

The climate is an Equatorial climate with high humidity and lots of rainfall. The rainy season varies, but it generally occurs between March and November. The temperature is moderate, but it can vary depending on the season. The relatively long growing season favors the production of annual and perennial crops. Temperature is one of important physical property of soil that affect crop yield. Soil gain temperature naturally from sun rays. It may further gain temperature due to heat of hydration when chemical fertilizer gets hydrated with water when applied. The high temperature of soil decreases enzyme activity, leaves turn to yellow, poor photosynthesis and declines crop yield.

Soil samples

The soil samples were randomly selected across the field. The material used was a quick connect Auger. Soil depths of 0-20 cm were mixed together and representative samples were obtained for air drying. A total of 18 samples were collected at different bomas sites from Magwi For each site composite soil samples were collected. With the absence of soil analysis laboratory in South Sudan, the soil samples were packaged, clearly labeled and taken to the Crop Nutrition Laboratory Service Ltd (CROP NUTS) in Nairobi, Kenya

Soil analysis

The soil samples obtained from the bomas site were prepared in labelled bags and transported to the Crop Nutrition Laboratory Service Ltd (CROP NUTS) in Nairobi, Kenya for analysis of physical and chemical soil properties. These samples were dried at room temperature, ground into powder, and analyzed in the laboratory for the analysis of different physical and chemical properties. These samples were analyzed for soil pH, Cation Exchange Capacity (CEC), organic matter, electrical conductivity (E Ce), macronutrients, and micronutrients using standard procedures.

The concentration of exchangeable K in the soil samples was determined by Flame Photometer as escribed by Tekalign [14]. The determination of

available P was determined by Olsen method [15]. Electrical conductivity (EC) of the soil samples were measured using conductivity meter [16]. Organic carbon (OC) of the soil was determined by using Walkley and Black method [17]. Total nitrogen (N) was determined by the micro Kjeldahl wet digestion and distillation method [18]. Soil pH was measured potentiometrically in H O and 1 M KCl solution at the 2 ratios of 1:2.5 for soil: H O and soil: KCl solutions using a 2 combined glass electrode pH meter [19]. Cation exchange Capacity (CEC) was measured by the ammonium acetate method [20]. Zn, Cu, Mn and Fe in soils was estimated by the method developed by Lindsay and Novell, [21], using DTPA (Diethyl Triamine Penta Acetic Acid) which was found useful for separating soils into deficient and non-deficient categories for Zn, Cu, Mn, and Fe by using atomic absorption spectrophotometer.

The interpretation of soil results was done using the Booker Tropical Manual [22]. Such analysis is important for assessing the suitability of the soil for growing

III. RESULTS AND DISCUSSIONS

Chemical soil characteristics

The chemical soil properties contents of the soil in the study were shown in Table 3. 1. pH is one of important parameter of soil fertility. It gives an idea about presence of water-soluble nutrients in the soils. Hence pH determination is important before type of crop chosen for soil. The requirement of pH is different for different types of crops [22 &24]. Brady found that a pH range of 6.5 to 7.5 is optimal for plant nutrient availability [25]. As evident from the table 1, pH value is ranges from 6.61 on sample site of Palwonganyi 2 and maximum was 8.35 on sample site of Sau 1. (Average: 7.1) in the different soil sample.

Plant growth is affected by pH in a universal way. Soil pH has an important influence on soil nutrient availability, solubility of toxic nutrient elements and cation exchange capacity [26].

[27] stated that some nutrients become unavailable if the soil pH is extremely acidic or alkaline. The reason for this is that they become insoluble at

specific pH levels. Usually, the optimal pH is somewhere between 6.0 and 7.5 because all plant nutrients are reasonably available in that range. According to the data, the soil pH ranged from slightly neutral to slightly alkaline and alkaline. The minimum pH value was found to be 6.61 on the sample site of Palwonganyi 2, while the maximum was 8.35 on the sample site of Sau 1. The high pH content may lead to development of phosphate, iron, and manganese deficiency due to fixation by high calcium and magnesium content.

Cation Exchange Capacity (CEC) serves as a measure of the total quantity of negatively charged binding sites in the soil, where essential plant nutrients like Ca, Mg, and K are adsorbed. Soils with a low CEC are more likely to develop deficiencies in potassium (K), magnesium (Mg²⁺), and other cations, while high CEC soils are less susceptible to leaching of these cations [28]. The soil in the study areas had CEC values between 8.92 and 17.6 cmol kg⁻¹. Higher CEC soils might be due to a moderate amount of organic matter in surface layers. The soils of the majority samples have a very low CEC. Low CEC have a limited capacity to hold more nutrients, which results in low soil fertility and reduced water-holding capacity, as indicated by Brown [29].

Carbon (OC) and organic matter (OM) is major content of soil. It increases soil fertility, water holding capacity, water infiltration, root penetration and decreases soil erosion and influence power of

holding CO₂ in atmosphere [30] & [31]. Organic matter of soil is determined by multiplying organic carbon in percentage by 1.72. The organic matter is measure of plant and animal decaying residue in soil. Soil organic matter content in all soils ranged from 3.71 to 5.00, with the mean value of 4.30. Usually, the optimal level of organic matter is somewhere between 2.0 and 8.0. The organic matter content of the soil samples was moderate. Furthermore, the variations in the amount of soil organic matter are likely due to differences in the rate of litter decomposition in the soils examined.

Electrical conductivity (EC) is determining health of soil. It is measure of water-soluble ionic nutrients present in the soil [32]. EC values ranges from 66.3 to 157 as/acm in study area (Table 3.1) which are normal to reference range. The highest value of EC was found to be 157 uS/cm in Sample Loa, while the lowest value of EC was 66.3 uS/cm found in sample Palwonganyi 1.

The exchangeable sodium percentage ranges from 1.16 to 2.35. The highest value of exchangeable sodium percentage was found to be 2.35 in Sample Palwonganyi 2, while the lowest amount of exchangeable sodium percentage was 1.16. Found to be in sample Sau 1. and in accordance with the EC rating, the soils of the study areas were non-saline and non-sodic soils [33].

Table 3.1: Soil properties of soils studied in Magwi County, Eastern Equatoria.

Sample Site	PH		CEC			O.M		Ec		ESP				
	Result	Guide	Guide	Result	Guide	Guide	Result	Guide	Guide	Result	Guide	Guide		
	Low	High	Low	High	Low	High	Low	High	High	Low	High	High		
Loa	7.68	6.00	6.80	14.7	15.00	30.00	4.25	2.00	8.00	157	<800	1.45	0	5
Moli	6.80	6.00	6.80	12.5	15.00	30.00	4.74	2.00	8.00	70.0	<800	1.52	0	5
Sau 1	8.35	6.00	6.80	17.6	15.00	30.00	4.11	2.00	8.00	174	<800	1.16	0	5
Pajok 1	6.94	6.00	6.80	11.1	15.00	30.00	3.95	2.00	8.00	68.0	<800	1.37	0	5
Pajok 2	6.98	6.00	6.80	11.4	15.00	30.00	3.99	2.00	8.00	88.0	<800	1.17	0	5
Pajok 3	6.73	6.00	6.80	10.9	15.00	30.00	3.71	2.00	8.00	90.0	<800	1.70	0	5
Palwonganyi	16.78	6.00	6.80	8.92	15.00	30.00	4.63	2.00	8.00	66.3	<800	2.17	0	5
Palwonganyi	26.61	6.00	6.80	11.4	15.00	30.00	5.00	2.00	8.00	80.0	<800	2.35	0	5

Macronutrient (Primary- Secondary Nutrients) status of studied soil samples

Lack of data on soil fertility status from soil sciences and other sources for the Magwi and other areas in South Sudan constrain soil fertility management plans needed for sustainable land use management systems. Nitrogen, phosphorus, and potassium, are mostly limit crop production. Therefore, understanding the nutrient status of the soils from Magwi County, Eastern Equatoria, South Sudan is important to forecast productivity, promote sustainability, and propose an appropriate technique for crop productivity sustainability.

Nitrogen is major nutrient required for plant growth. It gives deep green coloration to plant leaves [34]. All the plant absorbs nitrogen in the form of ammonium or nitrate ion. As evident from table 3. 2, The available range of nitrogen of all soil sample lies in the ranged from 0.11 to 0.21, with an average of 0.15%. The highest amount of nitrogen was found to be 0.21 in sample Pajok 3, while the lowest amount was found to be 0.11 in Sample Sau 1. Most of the sample showed lower availability of nitrogen. Although nitrogen is the most limited nutrient, it is necessary for chlorophyll production, cell division, protein synthesis, and overall plant vigor. Leaching, volatilization, and immobilization are all ways in which nitrogen can be easily lost from the soil. To retain nitrogen in the soil, it is necessary to manage these pathways. The availability of nitrogen is an important factor in increasing soil fertility. The deficiency of nitrogen causes uniform yellowing of older leaves, including veins. These leaves will eventually turn brown and die.

Phosphorus is one of important nutrient required for normal plant growth. It is used in photosynthesis for synthesis of carbohydrates and fats. It is necessary for seed germination, flowering and fruit formation [35]. Plants need large quantities of phosphorus, which is a macronutrient. It is crucial for root development, energy for biochemical processes, cell division and elongation, flower initiation, and fruit and seed development. The values of phosphorus in different soil samples ranged from 15.1 to 80.5, with an average of 80.45. The highest value of phosphorus was found to be 80.5 in Sample Palwonganyi 2, while

the lowest amount of phosphorus was 15.1. found to be in sample Pajok 3. The deficiency of phosphorus in soil may cause dark leaves with reddish purple tips and margins of young plants whereas the excess of phosphorus will not have a direct effect on the plant but may show visual deficiencies of Zn, Fe, and Mn. Potassium plays vital role in protein synthesis, photosynthesis. It maintains water balance of plant [36]. It an essential role in the photosynthesis and metabolism of plants, and important in carbohydrate breakdown which provides energy for plant growth. Potassium also increases drought resistance in plants and aid in reducing plant water loss [37]. In these soils, the results indicated that the soil had a higher potassium content. The potassium content was between 237 and 315, with the lowest value in Pajok 3 and the highest value in Pajok 2. Plants need potassium to transfer sugars and produce starch. This high potassium level can affect the plants' ability to absorb micronutrients, and that is probably the reason why they are showing those symptoms. However, it can also cause deficiencies of other nutrients, particularly nitrogen, calcium, and magnesium.

Calcium is considered a secondary nutrient. This nutrient does not play a secondary role in the growth and development of plants. It is required for the formation of new cells; therefore, it is necessary for roots, stems, and leaves to grow. It is also used by plants when they respond to pest and disease attacks. The results of the studied soils in the study areas indicated that soils had higher soil calcium content. Calcium concentration in soil solutions varies extensively. It ranges between 1170 in Palwonganyi 1 and 2890 in Sau1 samples site. Excess calcium is unlikely to cause toxicity by itself, but it can reduce the uptake of other nutrients, mostly cations, and can potentially cause deficiencies of other nutrients. High calcium levels significantly reduce the availability of phosphorus and micronutrients.

Magnesium is a secondary macronutrient that is crucial for plants. It is an important constituent of chlorophyll and is therefore required for photosynthesis. It is also a component of many plant enzyme systems and aids in their function. It's important for the growth and development of all plants. To produce the maximum economic yields, it is crucial to have an adequate level in the soil.

Magnesium is also an essential element for microbial growth and was implicated in microbial ecology in early studies of soil microbiology, since magnesium carbonate applied to certain soils increases the reproduction of soil bacteria [38]. Results of the study of soils in the study areas indicated that the soils had higher levels of magnesium content. The concentration of magnesium in soil ranges from 188

in Palwonganyi 1 to 393 in Pajok 1 samples site. High magnesium levels can lead to calcium deficiency. Plants need less magnesium than they need calcium. Increased magnesium use efficiency in crop plants can be achieved through the planting of magnesium-efficient crop species and genotypes within species.

Table 3. 2: Macronutrient status in studied soils of Magwi County Eastern Equatoria sites

Sample Site	Nitrogen (ppm)			Phosphorus (ppm)			Potassium (ppm)			Calcium (ppm)			Magnesium (ppm)		
	Result	Guide	Guide	Result	Guide	Guide	Result	Guide	Guide	Result	Guide	Guide	Result	Guide	Guide
	Low	High		Low	High		Low	High		Low	High		Low	High	
Loa	0.16	0.20	0.50	60.8	25	60	284	66	177	2210	681	794	266	68	109
Moli	0.15	0.20	0.50	18.1	25	60	286	66	177	1570	681	794	342	68	109
Saw 1	0.11	0.20	0.50	78.2	25	60	272	66	177	2890	681	794	213	68	109
Pajok 1	0.19	0.20	0.50	153	25	60	237	66	177	1300	681	794	393	68	109
Pajok 2	0.19	0.20	0.50	17.1	25	60	315	66	177	1360	681	794	373	68	109
Pajok 3	0.21	0.20	0.50	15.1	25	60	247	66	177	1290	681	794	328	68	109
Palwonganyi 10.14	0.20	0.50	56.3	25	60	238	66	177	1170	681	794	188	68	109	
Palwonganyi 20.12	0.20	0.50	80.5	25	60	308	66	177	1420	681	794	244	68	109	

Micronutrient status of studied soil samples:

Micro-nutrients (Mn, Cu, Zn, and Fe) are essential for plant growth, but plants require relatively small amounts of them, act as a co-factor for various enzymes associated with the metabolism of various organic molecules such as carbohydrates, nucleic acids, proteins and lipids [39]. Manganese is essential micronutrient in soil and played important role in photosynthesis and enzyme catalysis. Different soil samples (Table 3.3) had manganese content ranging from 57.5 to 157 ppm, with an average value of 103 ppm. Low manganese content levels cause interveinal chlorosis in young leaves, which is a gradual change from pale green to darker color next to veins, with no sharp distinction between veins and interveinal areas, as with iron deficiency.

Copper is activator of different enzymes like tyrosinase, ascorbic acid oxidase, lactase etc. The copper and zinc are a constituent of superoxide dismutase enzyme which catalyzes dismutation of superoxide radicals. The value of copper nutrient was found to vary from 0.53 to 3.93 ppm (average: 1.72

ppm) in different soil samples, as shown in Table 3. The deficiency of copper causes stunted growth, poorer pigmentation, wilting, and eventual death of leaf tips. However, excess copper can induce a deficiency of iron, which may be induced with very slow growth. It's possible for the roots to be stunted.

Zinc (Zn) is naturally present in the parent materials of soil. It is an important component of various enzymes that are responsible for driving many metabolic reactions in all crops [40]. It is important micronutrient of soil required for catalysis of different enzymes like aldolases, carbonic unhydrase. It is required for protein synthesis and auxin production. The value of zinc content ranges from 1.63 to 3.64 ppm, with an average of 2.70 ppm in different soil samples (Table 3). Zinc is a micronutrient that crops need in small amounts, but its significance in crop production has grown in recent years. It is considered to be the most yield-limiting micronutrient in crop production in various parts of the world [41]; [42];[43] & [44]. Insufficient zinc can result in decreased stem length and resetting

of terminal leaves, reduced fruit bud formation, mottled leaves, and interveinal chlorosis. Zinc deficiency has a negative impact on the development of root systems in crop plants. This may negatively affect the absorption of water and nutrients, which in turn may affect growth and yield. Zinc's low mobility in plant tissues is the reason why its deficiency most commonly occurs in younger leaves. The solubility of zinc in soils is highly influenced by pH and decreases with increasing soil pH.

Overall, zinc recovery efficiency varied depending on the applied rate and crop genotypes. Zinc has negative interactions with P, Cu, Fe, and Mn in the absorption of plants. The excess of Zinc indicates that a Fe deficiency will develop.

Iron is existing in soil in the form of ferrous and ferric ions. It is important micronutrient required for healthy plant growth. The growth and development of higher plants is greatly influenced by Iron (Fe). Iron has many functions in plants; however, its main role is to participate in many plants' metabolic functions, and it is also a component of many enzymes. The uptake of iron by crop plants exceeds that of all other essential micronutrients except chlorine. Table 3 shows that the iron content varied from 64.4% to 131.3%, with an average value of 90.83 ppm in different soil samples. The deficiency of iron shows that the veins remain conspicuous green, while the other leaf portions turn yellow and tend to whiteness.

Table 3. 3: Micronutrient (ppm) status in soils of Magwi County, Eastern Equatoria.

Sample Site	Manganese			Copper		Zinc			Iron			
	ppm											
	Result	Guide	Guide	Result	Guide	Guide	Result	Guide	Guide	Result	Guide	Guide
	Low	High		Low	High		Low	High		Low	High	
Loa	96.0	100	300	0.85	2.00	10.00	2.83	2.00	20.00	75.5	80	300
Moli	87.5	100	300	2.18	2.00	10.00	1.63	2.00	20.00	117	80	300
Saw 1	64.7	100	300	0.84	2.00	10.00	1.93	2.00	20.00	64.4	80	300
Pajok 1	152	100	300	3.79	2.00	10.00	3.64	2.00	20.00	77.4	80	300
Pajok 2	157	100	300	3.64	2.00	10.00	3.56	2.00	20.00	71.4	80	300
Pajok 3	150	100	300	3.93	2.00	10.00	3.04	2.00	20.00	74.9	80	300
Palwonganyi	167.0	100	300	2.00	2.00	10.00	3.00	2.00	20.00	115	80	300
Palwonganyi	257.5	100	300	0.53	2.00	10.00	2.20	2.00	20.00	131	80	300

IV. CONCLUSION

The study aimed to assess soil health and nutrient status in the Magwi County, the results indicated that the soils were generally, slightly acidic, slightly alkaline and alkaline (Mean = 7.03), low in CEC and medium in organic carbon, with high level in Ca, K, and in Mg contents. The total nitrogen and available phosphorous indicate low and medium contents in almost all soil samples. Generally, Zn and Cu were found to be in the low and medium categories respectively in some soils. Therefore, appropriate

intervention strategies to restore deficient nutrients must be implemented in areas with deficiencies in mineral nutrients. If these efforts are not taken into consideration, land degradation due to nutrient mining will increase to a point where it may be very expensive to restore.

Supplemental application of fertilizers containing nitrogen, phosphorus, and micronutrients will be required for sustainable crop production and the application of organic matter to improve the overall fertility of the soil. For wider spread adoption to address the issue of soil fertility in the Eastern

Equatoria should consider the altitude issue due to variations in soil health and nutrient content.

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