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Short Communication

Achieving Nutritional Security through Millets in India: Status and Way Forward

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A group of small seeded grasses known as millets have evolved to thrive in conditions of poor soil fertility, little humidity, and high temperatures. The earliest cultivated crops included millets. Millets were a staple food for the Indus valley inhabitants since 3,000 BC, according to the evidence. More than 130 nations presently cultivate them. Nutritious cereals that fall under the millets category include sorghum, pearl millet, finger millet, foxtail millet, proso millet, kodo millet, barnyard millet, little millet, etc. As of 2021, India (41%), Niger (12%), and China (8%) are the top three millet-producing countries. India ranks twelve among countries with high millet yields. Millets have been a mainstay of the human diet since the beginning of time. They have numerous health advantages in addition to being environmentally friendly due to their minimal production-related water and input requirements. Similar to rice and wheat, millets are cereals, however they are more nutrient-dense in terms of proteins, minerals, and vitamins. The three main millets grown in India are sorghum, pearl millet, and finger millet, often known as jowar, bajra, and ragi, respectively. They are a natural source of calcium, iron, zinc, and other minerals. They have more folic acid, calcium, iron, potassium, magnesium, and zinc than wheat and rice.

The Ministry of Women and Child Development, Government of India, announced 2018 to be the National Year for Millets and included the crop in its POSHAN MISSION. India has done exceptionally well when it comes to meeting the caloric needs and demands of her people, despite the fact that millets, although being rich sources of protein and antioxidants with great nutritional value, have never been considered fashionable meals. Almost every household in India is familiar with the flavor and advantages of millet, unlike a significant portion of the rest of the globe. Millets have long been a part of the Indian cuisine, particularly in rural areas, and they are still widely consumed today. 2023 has been proclaimed the International Year of Millets by the United Nations General Assembly. The main goal of the International Year of Millets is to enhance understanding of how millets can be useful in alleviating food injustice and inadequacy while also increasing awareness of the nutritional potential of millets.

Why do people prefer finer grains over coarse ones?

It is simpler to knead (process wet flour into dough) and roll rotis because wheat has gluten proteins that swell and form networks when water is added to the flour. The resulting chapattis are soft, which is impossible with millets that do not contain gluten. Fine grains are significantly easier to digest and absorb (for toddlers and elderly adults) and taste better (due to a high amount of carbs). They are so chosen over millets that are high in fibre.

Benefits of millets

Millets are climate smart crops. Due to their shorter growing season (70-100 days, as compared to 120-150 days for paddy/wheat) and lower water requirement (350-500 mm as compared to 600-1,200 mm), they are more resilient and drought-resistant (can grow in semi-arid locations and poor soil conditions).

- Although alternative grains often provide lesser yields than rice, they are more resilient and tolerant of the whims of climate change when grown in rainfed environments.
- They are environmentally friendly since they use less water, pesticide, and insecticide.

Health Benefits

- Compared to wheat and rice, millets have a higher nutritional content, making them a nutritious powerhouse. They are easily absorbed by newborns since they are naturally alkaline.
- They are abundant in minerals like calcium, iron, zinc, potassium, magnesium, and vital fatty acids as well as dietary fibre, B vitamins, antioxidants, and protein (which helps build muscle).

- They are low in glycemic index and gluten-free.

Initiatives required to promote millets

- More enticing dishes must be invented in order to popularise millets and make them a staple of the diet.
- Promotion of multigrain breakfast cereals as an alternative to morning energy beverages like boost.
- Along with wheat and rice, millets should also be included in the Public Distribution System (PDS).
- All millets should be included in Minimum Support Price (MSP). Now, only jowar, bajra, and ragi are supported by MSP.
- The PM POSHAN Scheme (Mid-Day Meal Scheme) should include millets.

Maize is a staple cereal crop grown in almost all parts of the world. It is a high yielding cereal grown successfully under rainfed environment and requires less capital. According to a study a yield of up to 7.5 t/ha is attainable under good management [1], but yield in Nigeria is below 5.0 t/ha due to low nutrient status of the soils, especially N, P and K. Much of the nutrients required by maize plants come from the soil, but the supply of nutrients is not able to meet the nutrient requirements for realizing higher yields. The use of fertilizers is therefore essential to fill the above gap between the crop needs for nutrients and the supply of nutrients from soil and available organic inputs ensuring the right rate and right time of fertilizer application.

Several researches conducted on nutrient omission have indicated different responses of maize to nutrient uptake and crop yield. A long-term permanent plot experiment conducted at the Regional Agricultural Research Station, Parwanipur, Nepal reported that application of phosphorus, potassium or both phosphorus and potassium along with nitrogen did not improve the yield of rice, indicating that phosphorus and potassium were not limiting yields [2]. Omission of phosphorus, potassium or both for wheat led to yield similar to those of nitrogen, phosphorus and potassium, indicating that the wheat did not respond to phosphorus and potassium. In a similar nutrient omission study, mean grain yields of rice had been reported to be 2.6, 6.1, and 6.3 t/ha in the nitrogen, phosphorus and potassium omitted plots, respectively during dry season [3]. The same treatments yielded 2.5, 3.2, and 4.0 t/ha in the nitrogen, phosphorus, and potassium omitted plots, respectively during the wet season. They stated that nitrogen and phosphorus were yield limiting nutrients, while the indigenous potassium supply was considerable to sustain crop production.

A comparison was made with seven soils using nutrient omission trials in Vanuatu with maize as test crop [4]. The findings indicated that relative top dry weight of maize was significantly affected by different treatments. The study revealed deficiencies of phosphorus in all soils tested, of nitrogen in four soils, of potassium in two soils and of sulphur in two soils. No other nutrient deficiencies had been detected. Optimization of major nutrients for lowland rice production in eastern Uganda was carried out [5] using nutrient omission trial for estimating indigenous nutrient supply of the major nutrients and response function. Application of nitrogen significantly increased yield components and consequently the grain yield of rice. The major limiting nutrient for lowland rice production is nitrogen and the soil nitrogen supplying potential can support yield target of 2.8 t/ha. Whereas the indigenous phosphorus and potassium supply can support yield target of up to 9.0 t/ha and therefore, not limiting at achievable yield targets of 6.0 t/ha.

There are several studies that examine the impact of site-specific nutrient management (SSNM) approach on fertilizer use primarily using field experiment. On-farm experiments to develop and test a new SSNM approach for eight key irrigated maize production domains of Asia located in six countries from 1997-1999 was carried out [6]. They hypothesized that maize yields, profit, plant nutrient uptake, and nitrogen use efficiencies can be significantly increased by applying fertilizer on a field-specific and cropping season-specific basis, i.e., through SSNM. They found that average grain yield increased by 0.36 Mg per hectare with SSNM as compared to current farmers' fertilizer practice in their study in cropping systems in Asia. Their results show that SSNM led to significant increases in nitrogen use efficiency. Average agronomic efficiency of applied nitrogen (kg grain yield increase per kg nitrogen applied) under SSNM was 15 kg kg^{-1}, apparent recovery efficiency of applied nitrogen (kg nitrogen taken up per kg nitrogen applied) 0.40 kg kg^{-1}, and partial factor productivity of applied nitrogen (kg grain yield per kg nitrogen applied) 52 kg kg^{-1}. Compared to the farmers' practice, average agronomic efficiency of applied nitrogen and recovery efficiency of applied nitrogen increased by almost 30 percent, partial factor productivity of applied nitrogen by six percent.

Analysis of the SSNM in irrigated maize systems of the Red River Delta was carried out on 24 farm fields as a comparison with farmers' fertilizer practice and found that SSNM results in a small yield increase of 0.19 tonnes per hectare on winter-spring season over farmers' fertilizer practice [7]. The authors also looked at the effect of SSNM on fertilizer use and profit and found that SSNM decreased the total fertilizer cost by about $2 per hectare in 1998 and by $22 per hectare in 1999. The average profit increase over farmers' fertilizer practice was $41 per hectare in 1998 and $74 per hectare in 1999. In a similar study, similarly, [8] explored the environmental impact and economic benefits of SSNM in irrigated maize systems in Asia, particularly in the Philippines, southern India, and southern Vietnam using on-farm trials, research data showed that SSNM led to higher efficiency of nitrogen use. While the annual nitrogen use was the same for SSNM and farmers' fertilizer practice in India, the reduction in fertilizer uses with SSNM averaged 10 percent in the Philippines, and 14 percent in Vietnam. In all the three locations, the estimated grain yields were significantly higher in SSNM than in farmers' fertilizer practice fields. In addition, the partial factor productivity of nitrogen increased significantly with

SSNM in the Philippines and Vietnam. This increase had been associated with increased plant use of nitrogen and reduced loss of nitrogen. Economic performance of SSNM had also been assessed using economic data. Gross revenue and gross return above fertilizer costs were higher for SSNM than non-SSNM farmers across the three countries. Although, their results showed that the practice of SSNM did not reduce the total input costs, it raised the net benefits of farmers by $169, $106, and $34 per hectare per year in India, the Philippines, and Vietnam, respectively. Studies of [9] in north-western India and [10] in China found similar results.

In a related study of a site-specific approach to nutrient management evaluation in 56 on-farm experiments with irrigated wheat and transplanted maize crops in north-west India, the result revealed that field-specific management of macronutrients increased yields of maize and wheat crops by 12% and 17% and profitability increased by 14% and 13%, respectively as compared to farmers' fertilizer practice [11]. Overall average yields with SSNM increased by 7% and profitability by 12%. Report of [12] indicated that the results of trials conducted on irrigated maize in different countries of south Asia revealed the benefit of SSNM, where fertilizer nitrogen rates significantly reduced by 10% to 20% at the experimental sites in China, Vietnam and Indonesia. Reduction in phosphorus requirement amounted to 20%, while reduction in potassium requirement of 15% has been found in Hanoi in the Red River Delta of north Vietnam.

An evaluation on the impact of SSNM in irrigated rice farms in the Red River Delta, northern Vietnam indicated that the impact analysis identified several directions that can be pursued to improve further the adoption of SSNM [13]. A pot experiment using SSNM for management of maize and rubber growing soil was carried out by [14]. The pot trial using maize and rubber showed that nitrogen, phosphorus and lime were limiting factors. However, order of limiting for maize has been found to be P > N > Lime, whereas for the rubber it was N > P > Lime. Rubber in the experimental field was reported to have been responded to nitrogen and phosphorus fertilization, corresponded to the pot trial. Furthermore, [15] also found that SSNM provided an increase in grain yield of about 0.5 t/ha and gave higher benefit than farmers' fertilizer practice. Fertilizer rates as estimated by SSNM has almost been met the requirement of crop, therefore it could save nutrients, especially nitrogen which was applied too high by farmers.

Considering the low fertilizer use by farmers in the northeastern Nigeria and the correspondingly lower yield compared to the other regions of the country, this experiment was designed to determine the most limiting nutrient for maize production on sandy soils of Maiduguri, Nigeria.

Materials and Methods

Site description

A field experiment was conducted during rainy seasons of 2018 and 2019 at the University of Maiduguri Commercial Farm, Maiduguri (11°48' N; 13º 13' E; 322 m above sea level), in Sudan savanna, Nigeria. The site has an average minimum and maximum monthly temperature of 28.5 and 32.8°C, respectively, with highest temperatures between March to July and the lowest temperatures between November to February. Average annual rainfall is between 500 to 600 mm. Rain distribution is unimodal, which starts on average from mid-June and lasts towards the end of September [16] The soil of the study area is sandy loam with poor physical properties [17] and inherently low in fertility.

Soil sample collection and preparation

Prior to the experiment four samples per replicate were bulked together to form a composite sample. After the experiment three

Properties	Values	
	2018	2019
Particle size distribution (g kg^{-1}):		
Sand	716	815
Silt	146	72
Clay	138	113
Texture	Sandy loam	Sandy loam
Bulk density (g cm^{-3})	1.74	1.68
$pH_{1:2.5}$ (water)	7.8	7.4
Electrical conductivity (dS m^{-1})	0.03	0.08
Organic matter (g kg^{-1})	2.57	2.84
Total nitrogen (g kg^{-1})	0.85	0.90
C:N ratio	1.75	1.85
Available Phosphorus (mg kg^{-1})	5.25	6.83
Exchangeable cations (cmol kg^{-1}):		
Potassium (K)	0.99	1.08
Sodium (Na)	0.31	0.29
Calcium (Ca)	0.80	1.90
Magnesium (Mg)	1.90	3.30
Exchangeable acidity (H + Al)	0.35	0.35
Cation Exchange Capacity (CEC)	5.44	5.82
Base saturation (%)	93.58	94.02

Table 1: Selected physical and chemical properties of the soil before commencement of the experiment.

samples from each plot were also bulked. The bulk samples from the field were prepared by air-drying and sieving through 2 mm. A 400 g sub-sample of the processed samples was carefully weighed and used for determination of soil properties such as particle size distribution, soil bulk density (the core method was used to determine bulk density), soil pH (water) and EC, soil organic C (combustion), total N, available P, exchangeable bases (K, Na, Ca, Mg), and CEC.

Treatments and experimental design

The experiment consisted of NPK omission plots and additional control and NPK + secondary and micronutrient treatments, making seven treatments. The treatment structure in the field were control (no fertilizer), PK, NK, NP, NPK, NPK + S + Ca + Zn + B, and NPK + S + Ca + Zn + B + Manure (cow dung). These were replicated three times in a randomized complete block design (RCBD) in plots sizes of 8 m by 8 m. Maize variety used was 2000 Synthetic TZEEY (yellow). Nutrients (NPK) were applied at rates requirements to achieve the expected attainable yield without nutrient limitation in the location. Application rate of 120:60:30 NPK kg/ha was used due to low rainfall and low potential maize production of the area, with attainable yield of 5-6 t/ha. Nitrogen was applied in three splits as follows: 1st application as basal, 2nd topdressing i.e., V6 (approx. 21 Days after emergence, DAE) and at 3rd topdressing i.e., V10 (approximately 42 DAE) using urea (46%). All other nutrients (P and K from SSP and MOP) were applied as basal at the time of planting. The amount of fertilizer applied per plot was calculated as follows Fertilizer (g/plot) = Nutrient application rate (kg/ha) x (100/% nutrient content) x (plot area/10,000) x 1000

Cattle manure was applied at 10 tonnes per hectare. The manure was well composted, dried and with low sand/soil content. The manure was sourced locally from one farm to ensure that the manure used in the area is of homogenous quality. Three samples of 500 g were taken after mixing thoroughly and taken to the laboratory for moisture content determination. After drying, 200 g subsamples were stored in clearly labelled sample bags for nutrient content analysis. Considerable amounts of manure (500 kg on dry weight basis) were procured and packed in large bags and stored to avoid wetting in the event of rain occurrence before application. At planting time, the manure heap was thoroughly mixed, weighed in bags, broadcasted and incorporated into the soil during land preparation. A spacing of 75 x 25 cm was followed for planting hybrid maize varieties in order to maintain a plant population of at least 53,000 plants/ha.

Field management practices

Treatment	Number of cobs/plot			Weight of cobs/plot (kg)		
	2018	2019	Mean	2018	2019	Mean
Control	43^{e*}	61^{c}	52^{d}	0.53^{g}	0.37^{e}	0.45^{b}
PK	79^{d}	102^{bc}	91^{c}	1.50^{f}	0.77^{e}	1.13^{b}
NK	85^{d}	92^{bc}	89^{c}	3.27^{e}	3.67^{d}	3.47^{b}
NP	109^{c}	159^{ab}	134^{b}	4.30^{d}	11.10^{c}	7.70^{a}
NPK	144^{b}	159^{ab}	152^{ab}	4.85^{c}	12.37^{bc}	8.61^{a}
NPK + Micro.	147^{b}	150^{ab}	148^{b}	6.03^{b}	13.70^{ab}	9.87^{a}
NPK + Micro + M	196^{a}	173^{a}	185^{a}	7.73^{a}	14.63^{a}	11.18^{a}
SE±	4.993	22.96	11.61	0.177	0.532	1.284

Table 2: Effect of nutrient omission on number and weight of cobs per plot of maize at harvest.

*Means followed by the same letter(s) within a column are statistically not significantly different at 5% level of probability according to the Duncan's Multiple Range Test.

Land preparation was carried out using conventional tillage. The plots were cleared and the residues from previous seasons' crops removed before ploughing and harrowing at a depth of 20 cm using tractor harrow in the first year and hand hoe in the second year. The plots of the first season were maintained in the second season to take advantage of the residual nutrient effects. The plots were weeded manually twice during the cropping season. First at 2 weeks after planting and the second at 4 weeks after planting.

Agronomic data collection

Timing parameters such as date of sowing, date of emergence, dates of fertilizer application and dates of weeding were recorded. Maize was harvested at the right time after physiological maturity when moisture content is less than 18%. Harvesting was done from a net plot of 4 m x 4 m. All the plants from a net plot were cut above the ground and measurements taken as described under data collection section.

Parameters measured at harvest were maize grain (kg), number of cobs, weight (kg) of the total maize stalks of each plot without cobs, weight (kg) of the cobs per plot, five cobs taken at random from each net plot, bulked and their weight immediately taken. The five cobs were shelled and grains and the cobs weighed. The data collected were subjected to Analysis of Variance (ANOVA) using statistical software *STATISTIX* (Version 10.0) and significant means were compared using Duncan Multiple Range Test at 5% level of probability.

Treatment	Weight of five unshelled cobs/plot (g)			Weight of five shelled cobs/plot (g)		
	2018	2019	Mean	2018	2019	Mean
Control	135.5^{e}	167.9^{a}	151.7^{c}	113.3^{c}	119.0^{a}	116.1^{b}
PK	182.6^{d}	170.5^{a}	176.5^{bc}	148.1^{bc}	113.7^{a}	130.9^{b}
NK	182.8^{d}	180.5^{a}	181.7^{bc}	160.9^{b}	118.3^{a}	139.6^{ab}
NP	230.9^{c}	160.8^{a}	195.9^{abc}	169.9^{b}	115.9^{a}	142.9^{ab}
NPK	261.6^{bc}	201.2^{a}	231.4^{ab}	189.3^{ab}	136.1^{a}	162.7^{ab}
NPK + Micro.	271.6^{b}	195.5^{a}	233.5^{ab}	174.8^{b}	144.5^{a}	159.7^{ab}
NPK + Micro + M	318.5^{a}	187.5^{a}	253.0^{a}	228.2^{a}	135.9^{a}	182.1^{a}
SE±	10.55	23.11	20.01	14.44	18.50	17.27

Table 3: Effect of nutrient omission on weight of unshelled and shelled cobs per plot.

*Means followed by the same letter (s) within a column are statistically not significantly different at 5% level of probability according to the Duncan's Multiple Range Test.

Treatment	Stalk yield (kg ha^{-1})			Grain yield (kg ha^{-1})		
	2018	2019	Mean	2018	2019	Mean
Control	1948^{e}	4042^{d}	4125^{c}	334^{g}	229^{e}	646.0^{c}
PK	3609^{d}	4636^{d}	9782^{bc}	938^{f}	479^{e}	1229.5^{bc}
NK	4859^{c}	8719^{c}	11709^{abc}	2042^{e}	2292^{d}	4448.0^{abc}
NP	6740^{b}	12010^{b}	16667^{ab}	2688^{d}	6938^{c}	7625.2^{ab}
NPK	6677^{b}	14563^{a}	20094^{a}	3031^{c}	7729^{bc}	8625.3^{a}
NPK + Micro.	7063^{a}	14229^{a}	15667^{ab}	3771^{b}	8563^{ab}	8250.2^{a}
NPK + Micro + M	7188^{a}	11029^{b}	17083^{ab}	4834^{a}	9146^{a}	8739.8^{a}
SE±	85.066	717.05	3129.4	110.69	332.59	2293.1

Table 3: Effect of nutrient omission on stalk and grain yields of maize.

*Means followed by the same letter(s) within a column are statistically not significantly different at 5% level of probability according to the Duncan's Multiple Range Test.

Results and Discussion

Selected soil physico-chemical properties of the experimental field

Soil physical and chemical properties of the experimental site are presented in Table 1. The sand fractions were higher in soils in both years than the silt and clay fractions and this translated into sandy loam texture. The slow rate of weathering and relatively young age of the soils was attributed to the low silt and clay fractions in soils [18]. The lower clay content in soil was also due to continues cultivation [19] which promotes further weathering and erosion processes as it shears and pulverizes the soil and changes the moisture and temperature regimes, which encourages the finer fraction to be carried away by erosion. The sandy loam textural class of the area indicates the homogeneity of soil forming processes and similarity of parent materials as reported by [20].

The soil pH measured in water varied from slightly alkaline to neutral in 2018 and 2019, respectively [1]. This may be due to low amount of rainfall leading to lower leaching of soil cations [18,21]. It is indicative that the pH range was optimum for cultivation of most crops. The organic carbon content (Table 1) was low in both years. Soil organic carbon plays an important role in nutrient availability and soil aggregate formation [22]. The generally low levels of soil organic matter in the study area might be due to the effect of sparse vegetation cover and persistent cultivation [21], coupled with high temperature which resulted to soils rapid mineralization. For example, studies conducted by [18], [21], and [23], opined that intensive cropping and tillage practices destroy soil structure through compaction, loss of soil moisture, increased bulk density and make such soils susceptible to soil wash and loss of basic cations. The total nitrogen of the area was rated low, below 1.5 gkg^{-1} critical level recommended [24]. However, the lower total nitrogen across the years may be attributed to loss of total nitrogen through leaching and rapid mineralization due to exposure to solar radiation and to high temperatures which characterize the study area [25]. Available phosphorus was found to be low in both years as also observed by [24], indicating serious deficiency problem of phosphorus. Despite the addition of phosphorus bearing fertilizers in the first year, the available phosphorus level of the second year is still low, indicating inherently low level of phosphorus in the soils of the study area. The mean value of exchangeable K was rated high in both years as per [24] ratings. The higher exchangeable K obtained in the soil could be due to the inherently higher amount in the soil during soil formation [25].

Effect of nutrient omission on yield parameters of maize

Effect of nutrient omission on number of cobs per plot and weight of cobs per plot

The effect of nutrient omission on number of cobs per plot and weight of cobs per plot are presented in table 2. Significant

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