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RESEARCH ARTICLE

Improving Primary Nutrients (NPK) Use Efficiency for the Sustainable Production and Productivity of Cereal Crops: A Compressive Review

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Abstract
Nutrient Use Efficiency (NUE) is the capacity of certain crops to use the available nutrients for growth, development, and productivity. Enhancing the efficiency of nutrient utilization by cereals is an admirable objective and a major problem for the fertilizer sector and agriculture as a whole. Nutrient Use Efficiency (NUE) is a critical concept in the evaluation of cereal production systems. Therefore, this study aimed to review methods for improving the efficiency of primary nutrient (NPK) use in cereals (Barley, Rice, Wheat, Maize, Sorghum, and Sugarcane) for sustainable production and productivity. Soil, plant water, and fertilizer management can have important impacts on the nutrient-use efficiency of cereals. Nutrient utilization aims to maximize the overall performance of cropping systems by providing the crop with the most inexpensive sustenance possible, while reducing nutrient losses from the field. The NUE takes care of some, but not all, of that performance. Thus, in addition to NUE, total productivity must is one of the aims of system enhancement. The question being posed and, frequently, the spatial or temporal scale of interest for which trustworthy data are available, dictate the most appropriate approach to NUE. For N, P, and K, the partial nutrient balance (the ratio of nutrients removed by crop harvest to fertilizer. Although opinions differ, agronomic nutrient use efficiency is the foundation for both economic and environmental efficiency. Economic and environmental efficiencies arise from increased agricultural efficiency. Therefore, different researchers have investigated ways to improve the nutrient use efficiency of cereals by using mechanisms including optimizing nutrient usage, nano-fertilizer usage, breeding for nutrient use efficiency, and precision farming.

Keywords: Primary plant nutrients; Nutrient uptakes; Nutrient use efficiency; Cereal crops

Introduction

Meeting societal demand for food is a global challenge, as recent estimates indicate that global crop demand will increase by 100–110% from 2005 to 2050 (Ali et al., 2020; Hunter et al., 2017). Others have estimated that the world will need 60% more cereal production between 2000 and 2050 (FAO, 2017), whereas others have predicted that food demand will double within 30 years, equivalent to maintaining a proportional rate of increase of more than 2.4% per year. It is quite difficult to fulfill such a demand sustainably, particularly in light of historical trends in grain yields, which have been linear for almost 50 years with slopes of barely 1.3% to 1.2 percent of the 2016 yields (FAO, 2017). The requirement for additional food grain can be met either by bringing more area under cultivation or by increasing the productivity and efficiency of existing crop varieties. Cereal crops are cultivated worldwide in large quantities. Since the Green Revolution began, the production of high-yielding cereals (maize, wheat, and rice), cotton, and sugarcane has significantly increased. Cereals especially, rice (*Oryza sativa* L.), maize (*Zea mays* L.), and wheat (*Triticum aestivum* L.) are essential commodities on which human nutrition is based. Expanding population and food demand have required higher production, which has been achieved by increasing fertilization, especially the primary macronutrients. Primary macronutrients play a very important role in improving the yield and quality of crops. The three main elements are nitrogen, phosphorus, and potassium (N, P, and K), which are required in abundance. They must be readily available in soil media or fertilizers (Isreal & Yonas, 2021).

Among the nutrients, nitrogen (N) is the fundamental nutrient that is needed the most for crop production while N deficiencies result in yellowing crop leaves and reduced tillering of cereal crops. Phosphorus (P) is a vital nutrient for plant growth and productivity that modifies cell division, enzyme activity, and carbohydrate processes (Malhotra et al., 2018). Moreover, phosphorus also plays a vital role in cellular processes by maintaining the membrane structure, synthesizing bimolecular molecules, and forming high-energy molecules (Malhotra et al., 2018).

Improving NUE and water use efficiency (WUE) has been listed among today's most critical and daunting research issues (Thompson, 2012). NUE is a critically important concept for evaluating crop production systems and can be greatly affected by fertilizer management, as well as soil- and plant-water relationships. NUE indicates the potential for nutrient loss to the environment from cropping systems, as managers strive to meet the increasing societal demand for food, fiber, and fuel (Paul et al., 2015). NUE measures are not measures of nutrient loss, because nutrients can be retained in the soil, and systems with relatively low NUE may not necessarily be harmful to the environment, whereas those with high NUE may not be harmless (Paul et al., 2015). We provide examples of these situations later in the chapter that illustrate why the interpretation of NUE measurements must be performed within a known context.

Sustainable nutrient management must be both efficient and effective in delivering the anticipated economic, social, and environmental benefits. As the cost of nutrients increases, profitable use places increased emphasis on high efficiency, and greater nutrient amounts from higher-yielding crop removal means that more nutrient inputs will likely be needed and at risk of loss from the system. Providing a society with sufficient quantity and quality of food at an affordable price requires that production costs remain relatively low, while productivity increases to meet the projected demand. Therefore, productivity and NUE should be increased. These factors have spurred efforts by the fertilizer industry to promote approaches to best management practices for fertilizers, such as 4R Nutrient Stewardship, which focuses on the application of the right nutrient source, at the right rate, in the right place, and at the right time (IPNI, 2012) or the Fertilizer Product Stewardship Program (Fertilizers Europe, 2011). These approaches consider the economic, social, and environmental dimensions essential to sustainable agricultural systems and, therefore, provide an appropriate context for specific NUE indicators. NUE appeared on the surface as a simple term. However, a meaningful and operational definition is considerably complex because of the number of potential nutrient sources (soil, fertilizer, manure, atmosphere [aerial deposition], etc.) and the multitude of factors that influence crop nutrient demand (crop management, genetics, and weather). The concept is further stressed by variations in the intended use of NUE expressions, and because these expressions are limited to data available rather than the data most appropriate for interpretation.

The objective of nutrient use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop, while minimizing nutrient losses from the field and supporting agricultural system sustainability through contributions to soil fertility or other components of soil quality (Tamirat, 2019). NUE addresses some aspects of that performance but not all (Mikkelsen et al., 2012). The most valuable NUE improvement contributed the most to the overall cropping system performance. Therefore, management practices that improve NUE without reducing productivity or increasing potential for future productivity are likely to be the most valuable. If the pursuit of improved NUE impairs current or future productivity, the need for cropping fragile land is likely to increase. Fragile lands usually support systems with lower NUE that also use water less efficiently. At the same time, as nutrient rates increase towards an optimum, productivity continues to increase, but at a decreasing rate, and NUE typically declines (Barbieri et al., 2008). The extent of the decline is determined by source, time, and place factors; other cultural practices; and soil and climatic conditions. Hence, this review was undertaken to provide information on improving primary macro-nutrient use efficiency in cereal (Barley, Rice, Wheat, Maize, Sorghum, and Sugarcane) crop plants.

Nutrient Management Practices

It is necessary to understand the possible effects of crop management techniques, such as mulching, minimum tillage, NPK fertilizers, balanced nutrient application, cereal crop yield, and household financial returns, to boost cereal yields and ensure sustainable productivity in smallholder farms. Nutrient application rate and NUE mostly have an inverse relationship (Fageria et al., 2015). Plants can take up the required amount of nutrients from the soil, and the unabsorbed nutrients either remain in the soil or are lost to the environment through several mechanisms (Tilman et al., 2002; Yang et al. 2019). Globally, the fertilizer recovery efficiency of plants is low (Omara et al., 2019; Chien et al., 2016; Cui et al., 2010; Ladha et al., 2005). Our results showed that the estimated global NUE values for cereal crops were 33% of N (Raun & Johnson, 1999), 16% of P (Dhillon et al., 2017), and 19% of K (Dhillon et al., 2019). Omara et al. (2019) also re-ported the world nitrogen use efficiency of 35%. This means that a total–65-67% of N, 84% of P, and 81% of K fertilizers remain unaccounted for and either remain in the soil or are lost to the environment. Ladha et al. (2005) reported that the N-recovery efficiency by the first crop is about 30% to 50%. Numerous factors, such as fertilizer application rate, timing, and techniques (Sharma & Bali, 2017), genotypes (Li et al., 2020), cropping system, native soil nutrient supply, and environment (Chen et al., 2018; Xu et al., 2014), to name a few, influence the fertilizer recovery efficiency. The leaching potential before peak N absorption increased when N fertilizer was applied before planting. Therefore, increasing NUE is a crucial and unrivaled strategy in contemporary agriculture to ensure that there is sufficient food to feed the growing human population while maintaining ecosystem services and lowering expenses.

Approaches to improve NUE in Cereal production

Improving NUE requires fundamental understanding of nutrient management. Below are some NUE improvement mechanisms applied in cereal production.

Soil management

Adoption of organic inputs: Unlike conventional agriculture, organic farming (OF) is mainly dependent on nutrient recycling, biological N fixation, and crop rotation (Timsina, 2018; Chmelíková et al., 2021). Recently, the use of organic fertilizers has become a better strategy to replace chemical fertilizers because of their ability to raise organic matter (SOM) concentration, yield, yield quality, and environmental reclamation (Song et al., 2015; Tesfaye, 2018). In addition, its use in arable land to enhance soil organic matter was adopted as an important strategy to boost food production, ensure food security, and mitigate climate change during the "4 per 1000 initiative" at COP 21 (UNFCCC, 2015). Chmelíková et al. (2021) demonstrated that OF systems had the highest nitrogen use efficiency and a lower N balance than conventional farming practices. Nutrient stewardship*:* The rational use of chemical fertilizers enhances crop growth and productivity, whereas excessive use results in potential yield reduction and adverse effects on the environment (Chandini et al., 2019; Tripathi et al., 2020). However, the use of appropriate sources, rational rates, appropriate timing, and effective application methods is the most important approach for solving the aforementioned challenges (Giday, 2019; Li & Jin et al., 2012). Nutrient-use efficiency can be increased by better matching the temporal and spatial nutrient supply with plant demand (Tilman et al., 2002). Therefore, the adoption of effective nutrient sources is an effective management approach for improving NUE and achieving higher crop yields.

Use of modified fertilizer: Nitrogen from conventional urea can easily be lost from the soil-plant system because of its dynamic nature (Zhu et al., 2020). Accordingly, a modified fertilizer is required to reverse its negative effects on soil, plants, and the environment. Different types of slow-release fertilizers (SRF) have been developed to improve NUE and reduce potential environmental losses (Giday, 2019; Giday et al., 2014). For example, controlled-release fertilizers (CRF) and nitrification inhibitors (NI) can either slow down nutrient-release patterns and/or interfere with nutrient transformation processes and reduce their loss (Singh et al., 2018). It potentially delays the N release pattern and reduces N losses, which may improve the synchronization potential between crop demand and soil N supply (Giday et al., 2014). A meta-analysis conducted in China revealed that the application of CR urea significantly improves crop yield and NUE (Zhu et al., 2020). In addition, meta-analysis results demonstrated that the use of enhanced efficiency nitrogen fertilizer could increase yield by 5.7% and N uptake by 8% (Linquist et al., 2013).

Adoption of the root-zone fertilization approach: Split-surface broadcasting (SSB) is a widely adopted fertilization method that may enhance yield and NUE, but it is labor-intensive. The use of slow/CRU has been proposed as a decisive approach to reduce nutrient loss and thereby enhance yield and NUE over conventional urea (Zhu et al., 2020), but it is highly expensive. Therefore, one-time root-zone fertilization (RZF) has been proposed as a decisive approach to solving the aforementioned challenges. Optimal matching of the soil nutrient supply through the application of nutrients in the root zone of the crop is one of the most important strategies for enhancing NUE, maintaining high and stable grain yields, and protecting the environment (Jiang et al., 2019). One-time RZF is the approach of applying all fertilizers at one time during the plant's entire growth stage. This has been proposed as a better approach to replace traditional fertilizer application practices. A two-year field experiment in China revealed that RZ N fertilization has a higher yield potential (approximately 11.55%) than SSB (Jiang et al., 2019). It also increased N apparent recovery efficiency from 14.3-37.8% and total N uptake by 7.2-13.5% compared with SSB treatments, while it decreased N losses by 11.2–24.2%. In addition, Liu et al. (2017) showed that the RZF of urea enhanced the grain yield of rice (about 19.5%), macronutrient accumulation and uptake, and apparent N recovery efficiency over farmer fertilizer practice in both sandy and loam soils. A two-year field experiment revealed that one-time RZF increased maize yield by

4%, apparent N recovery efficiency by 18%, and improved nitrogen agronomic use efficiency, physiological efficiency, and partial factor productivity compared with SSB in the Anhui province of China (Jiang et al., 2019). Therefore, adopting one-time RZF is an appropriate fertilization approach to reduce labor costs and enhance yield, NUE, and potential nutrient loss to the environment. Use of plastic mulch: Plastic mulch helps increase soil temperature, preserve soil moisture, conserve soil, reduce weed pressure, boost grain yield, and result in more efficient use of nutrients (Bahadur et al., 2018; Kasirajan & Ngouajio, 2012). In addition, it enhances both macro-and micronutrient availability in soil and water use efficiency, reduces nitrate leaching, and prevents runoff and soil loss. Despite their potential advantages, conventional polyethylene mulches cause major waste disposal problems and are agronomic, economic, and environmental challenges. However, this problem has led to the development of biodegradable and photodegradable mulches (Kasirajan & Ngouajio, 2012) that are easily degradable and have lower environmental costs.

Plant management

Adoption of nutrient-efficient genotypes: Development and preferential planting of high-yield and high-efficiency cultivars are important steps to ensure food security, reduce fertilizer use, and mitigate environmental pollution (Chen et al., 2013). Different genotypes vary in terms of their N uptake and utilization potential. This variation might be associated with root morphology (length, volume, thickness, and surface area of roots), the potential of the crop to absorb and solubilize nutrients in the rhizosphere, and the balance between source-sink relationships (Fageria et al., 2015; Ladha et al., 2005). Depending on the grain yield achieved at different nitrogen levels, maize cultivars were grouped into four categories based on their nitrogen use efficiency, as reported by Chen et al. (2013). These are (i) efficiency efficiency (EE) (efficient at both low and high N levels), (ii) high-N efficiency (HNE) (efficient only at high N levels), (iii) low-N efficiency (LNE) (efficient only at low N levels), and (iv) nonefficient-nonefficient (NE) (inefficient at both low and high N levels). The identification of genetic variation in crops regarding nutrient acquisition and internal use efficiency can help identify, select, and use relevant crop genotypes with greater NUE for sustainable production. Therefore, selecting NUE-efficient genotypes reduces the intensified use of fertilizer and has economic and environmental benefits.

Crop rotation and using biological N-fixing crops: Growing the same crop in the same field over many years (known as mono-cropping) gradually decreases soil productivity because of its over-reliance on external inputs. Suitable adoption of crop sequencing is a vital approach for decreasing the use of chemical fertilizers and improving NUE. Biological N fixation (BNF) is a vital approach in the N cycle, which can help the crop by supplying nitrogen and replenishing the soil N pool (Yassine & Belhadj, 2012). The inclusion of legume crops in the agricultural field fixes free atmospheric nitrogen and makes it available for the succeeding crops grown in the sequence, reducing chemical N demand and nitrate leaching (Fageria et al., 2015), which in turn improves yield and NUE. Management of biological stress*:* Pests, diseases, and weeds (PDW) continue to play a major limiting role in agricultural production. Crops infested with PDW have lower nutrient absorption potential and photosynthetic efficiency, which results in low yield and resource use efficiency. Tamene et al. (2016) demonstrated that poor weed management increases competition for soil nutrients, moisture, and sunlight, which affects resource use efficiency and crop productivity. Therefore, maintaining these factors at the threshold level is important for enhancing yield and NUE (Singh et al., 2018).

Integrated soil-crop system management approach

Achieving high yield and resource use efficiency simultaneously is a consensus that requires integrated adoption and application of soil and crop management approaches. Although world population and food demand are booming unprecedent-edly, the crop yield is stagnating in many parts of the world and the fertilizer use efficiency is declining quickly, particularly in high fertilizer supply regions such as China. To mitigate such challenges, an integrated soil-crop system management (ISSM) approach was developed in China to improve yield and NUE without further increase in chemical fertilizer while reducing environmental pollution (Zhang et al., 2011). The management techniques employed in the ISSM paradigm have three major principles: (i) taking all possible and important measures to enhance the quality of soil, (ii) accounting for and cohesive use of different nutrient resources and matching nutrient supply with crop requirements, and (iii) integrating soil and nutrient management practices with the high-yielding production system (Jiao et al., 2018; Zhang et al., 2011).
Wang et al. (2020) in their 11-years field experiment in China reported that adoption of ISSM practices could result in relatively at par maize yield with high yielding practices (HY), but it was increased by 27% over farmers' practice (FP). Moreover, it significantly increased nitrogen recovery efficiency, agronomic use efficiency, and partial factor productivity over HY and FP, and significantly reduced the N surplus. In addition, it reduced reactive N losses by 47% and 20% and greenhouse gas (GHG) emissions by 34% and 13%, respectively, compared with HY and FP, respectively (ibid). Based on a 7-years field plot (2009-2016), Zhang et al. (2019) summarized that the adoption of ISSM can be an effective agricultural management approach to enhance yield, phosphate utilization, and soil available phosphorous. Therefore, the adoption of an ISSM strategy is an effective approach for enhancing yield, improving NUE, and reducing environmental pollution.

Factors Influencing NPK Use Efficiency

Nutrient Use Efficiency (NUE) depends on several factors, such as the capacity of plants to take up nutrients effectively from the soil, internal transport, and storage remobilization of nutrients (Mikkelsen et al., 2012). It also indicates the ability of crops to produce the maximum yield while efficiently utilizing nutrients (Fixen et al., 2015). It is a critical factor for assessing crop production processes, which are significantly influenced by the dynamic relationship between soil, plants, and water, as well as nutrient management. It provides suitable solutions to managers who aim to satisfy the growing societal demand for food, fiber, and fuel against nutrient losses to the atmosphere from cropping systems. The aim of NUE enhancement is to enhance the productivity of cropping systems by providing economically optimal nourishment to the crop with minimum loss of nutrients from the field and ensuring the sustainability of the agricultural system by contributing to soil fertility and other components of soil quality.

Nutrient Use Efficiency Terminology

The nutrient use efficiency can be expressed in several ways. Mosier et al. (2004) described 4 agronomic indices commonly used to describe nutrient use efficiency: partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Crop removal efficiency (removal of nutrients from harvested crops as a percentage of nutrients applied) is also commonly used to explain nutrient efficiency. Available data and objectives determine

which term best describes nutrient use efficiency (Terry, 2008). Fixen (2005) provides a good overview of these terms with examples of how they might be applied.
The apparent use efficiency of fertilizer nutrients that are applied but not absorbed by the crop is affected by several factors, including leaching, erosion, denitrification (or volatilization in the case of N), and the possibility that they will be momentarily immobilized in soil organic matter before release (Terry, 2008). Dobermann et al. (2005) introduced the term system-level efficiency to account for contributions of added nutrients to both crop uptake and soil nutrient supply.

Current Status of Nutrient Use Efficiency

The single-year N fertilizer recovery efficiencies averaged 65% for maize, 57% for wheat, and 46% for rice according to a recent analysis of global data on N usage efficiency for cereal crops from researcher-managed experimental plots (Ladha et al., 2005). However, the efficiency achievable on a farm is not accurately reflected in the experimental plots. Lower nutrient usage efficiency is often the result of variations in the size of agricultural operations and management techniques (e.g., tillage, planting, weed and pest control, irrigation, and harvesting). Farmers seldom recover more than 50% of their nitrogen and typically recover considerably less. A review of the best available information suggests that the average N recovery efficiency for fields managed by farmers ranges from approximately 20% to 30% under rain-fed conditions, and 30% to 40% under irrigated conditions (Terry, 2008).
Cassman et al. (2002) looked at N fertilizer recovery under different cropping systems and reported 37% recovery for corn grown in the north-central U.S. They found that N recovery averaged 31% for irrigated rice grown by Asian farmers, and 40% for rice under field-specific management. In India, N recovery averaged 18% for wheat grown under poor weather conditions but 49% when grown under good weather conditions. Weather is an uncontrollable factor that affects fertilizer recovery, but management is something that can be managed.

Common Measures of NUE and their Application

Efficiency, in simple terms, is the achievement of desired outcomes with the lowest cost (Reich et al., 2014). In simplest terms, Nutrient Use Efficiency can be expressed at three different levels: at the leaf level, which is the potential maximum photosynthetic rate for certain nutrient content; at the plant level, which is the ratio of biomass produced to the total nutrient uptake; and at the crop level, which is the ratio of total biomass produced to the amount of nutrients available for uptake from soil (Ewel & Hiremath, 1998). In agronomic or operational terms, it is the differential response of crops/genotypes to yield when grown in nutrient-deficient soils (George et al., 2012). Excellent NUE measurements and common NUE terms are presented, along with their applications and limitations. The primary question addressed by each term and the most typical use of the term are listed in figure 2 (Dobermann, 2007).

Partial factor productivity (PFP) is a simple production efficiency expression calculated in units of crop yield per unit of nutrient applied. It is easily calculated for any farm that maintains input and yield records. It can also be calculated at regional and national levels, providing reliable statistics on input use and crop yields. However, partial factor productivity values vary among crops in different cropping systems because crops differ in their nutrient and water requirements. A comparison between crops and rotations is particularly difficult if it is based on fresh matter yields, because they differ greatly depending on the crop moisture content (e.g., potato vs.

cereals). Therefore, geographic regions with different cropping systems are difficult to compare using this indicator (Davis & Quick, 1998).

Agronomic efficiency (AE) was calculated as units of yield increase per unit of nutrients applied. It more closely reflects the direct production impact of an applied fertilizer and relates directly to economic return (Jagadish et al., 2021). Only once study plots with no nutrient input have been put into practice on the farm can the yield be obtained without nutrient input, which is necessary for calculating AE (Paul et al., 2015). The NUE of the applied fertilizer is frequently underestimated if it is computed using data from yearly trials rather than long-term trials, because of the residual effects of the application on subsequent crops. According to Dobermann (2007), long-term experiments are necessary to estimate the long-term effects of fertilizers on crop output.

Partial nutrient balance (PNB) is the simplest form of nutrient recovery efficiency and is usually expressed as nutrient output per unit of nutrient input (a ratio of "removal to use"). Less frequently it is reported as "output minus input." PNB can be measured or estimated by crop producers as well as at the regional or national level. Often, the assumption is made that a PNB close to one suggests that soil fertility will be sustained at a steady state. However, using a PNB of one as an indicator of soil fertility sustainability can be misleading, especially in regions with very low indigenous soil fertility and low inputs and production, such as sub-Saharan Africa, as the balance calculation is a partial balance and nutrient removal by processes, such as erosion and leaching, are typically not included (Paul, 2014). In addition, all nutrient inputs were rarely included in the balance calculations; thus, the modifier was partial in the term. Biological N fixation, recoverable manure nutrients, biosolids, irrigation water, and the atmosphere can all be nutrient sources, in addition to fertilizers.

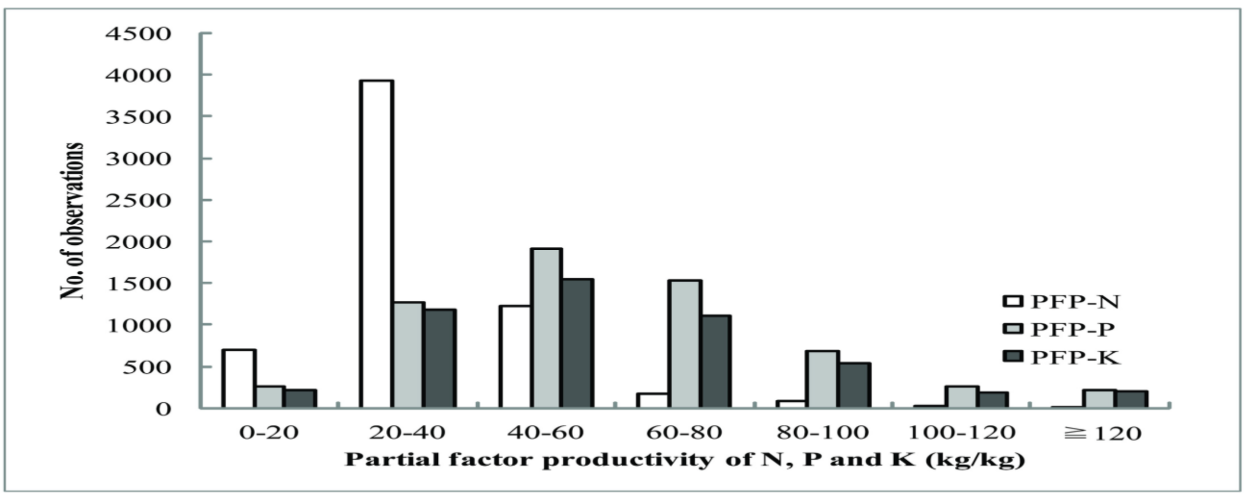

Figure 1 Distribution of the partial factor productivity of N, P, and K fertilizers (PFP-N, PFP-P, and PFP-K) in wheat in China. Source: Limin et al., 2016)

Nutrient inputs greatly outweigh nutrient removal at values far below 1, indicating preventable nutrient losses and the need for enhanced NUE (Suresh et al., 2017). However, attainable values are soil-specific and cropping systems. A PNB greater than 1 means more nutrients are removed with the harvested crop than applied by fertilizer and/or manure, a situation equivalent to "soil mining" of nutrients. This situation may be desirable if the available nutrient content in the soil is higher than that recommended. However, when the soil nutrient concentration is at or below the recommended levels, PNB >1 must be regarded as unsustainable (Suresh et al., 2017). Over the short term and on individual farms, PNB can show substantial fluctuations owing to cash flow and market conditions, especially for P and K. Therefore, the long-term assessment of PNB over several years is more useful (Zebarth et al., 2009). This is illustrated in Figure 1.

Apparent recovery efficiency (RE): One of the more complicated NUE expressions is apparent recovery efficiency (RE), which is usually described as the difference in nutrient uptake in the above-ground plant sections between the treated and unfertilized crops with respect to the amount of nitrogen provided. Scientists examining the nutritional response of crops frequently choose this as their preferred NUE expression (Addisu, 2022). Similar to AE, it is necessary to measure the concentration of nutrients in crops, which can only be assessed when a nutrient-free plot has been established (Prakash et al., 2021). Similar to AE, when calculated from annual response data, it will often underestimates long-term NUE (Paul, 2014).

Worldwide use of various fertilizers has made a remarkable contribution to increasing food production. It has been observed that nutrient inputs are responsible for 30–50% of crop yield (Meena et al., 2020). The recovery efficiency (RE) of Nitrogen, Phosphorus and Potassium fertilizers is approximately 20–40, 15–20, and 40–50%, respectively, while for secondary and micronutrients, it is considerably lower, ranging from 5% to 12% (Mandal et al., 2022). The important causes of low and declining crop responses to fertilizer nutrients include continuous nutrient mining from the soil due to imbalanced fertilizer use (7:2.8:1:NPK), leading to the depletion of some major, secondary, and micronutrients, such as N, K, S, Zn, Mn, Fe, and B (Kadyampakeni & Chinyukwi, 2021; Nadeem & Farooq, 2019). The reduction in the use of organic nutrient sources such as FYM, compost, and the integration of green manures/grain legumes in cropping systems has led to soil degradation. After several years of intensive research on nutrient management, field-specific fertilizer recommendations have been developed for almost all cultivated crops (Chivenge et al., 2022). The recommendations developed tell us about the amounts of different nutrients needed on a hectare basis and the time of application. Such blanket recommendations, which largely did not take into account the variability in the inherent soil fertility and other edaphic characteristics, resulted in the over-application of nutrients in some areas and under-application in others (Seth et al., 2020). This resulted in wastage of nutrients and low NUE. Research conducted in many Asian countries, including northwest India, has depicted the limitations of the conventional approach of fixed-rate, fixed-time (blanket) fertilizer recommendations (Singh et al., 2020). However, recognizing the defects in the blanket recommendations of nutrients, the concept of site-specific nutrient management (SSNM) of nutrients was developed. The original concept of SSNM for managing farm nutrient variability was first developed for rice in Asia (Arouna et al., 2021).

Internal utilization efficiency (IE) was defined as the yield of total nutrient uptake. It varies according to genotype, environment, and management. A very high IE value suggests a deficiency of this nutrient. Low IE suggests poor internal nutrient conversion due to other stresses (deficiencies of other nutrients, drought stress, heat stress, mineral toxicities, pests, etc.) (Zebarth et al., 2009).

Physiological efficiency (PE) is defined as the yield increase with an increase in crop uptake of nutrients in the aboveground parts of the plant. Similar to AE and RE, it requires a plot at a site where the nutrient of interest has not been applied. It also requires the measurement of nutrient concentrations in the crop, and is mainly measured and used in research (Zebarth et al., 2009).

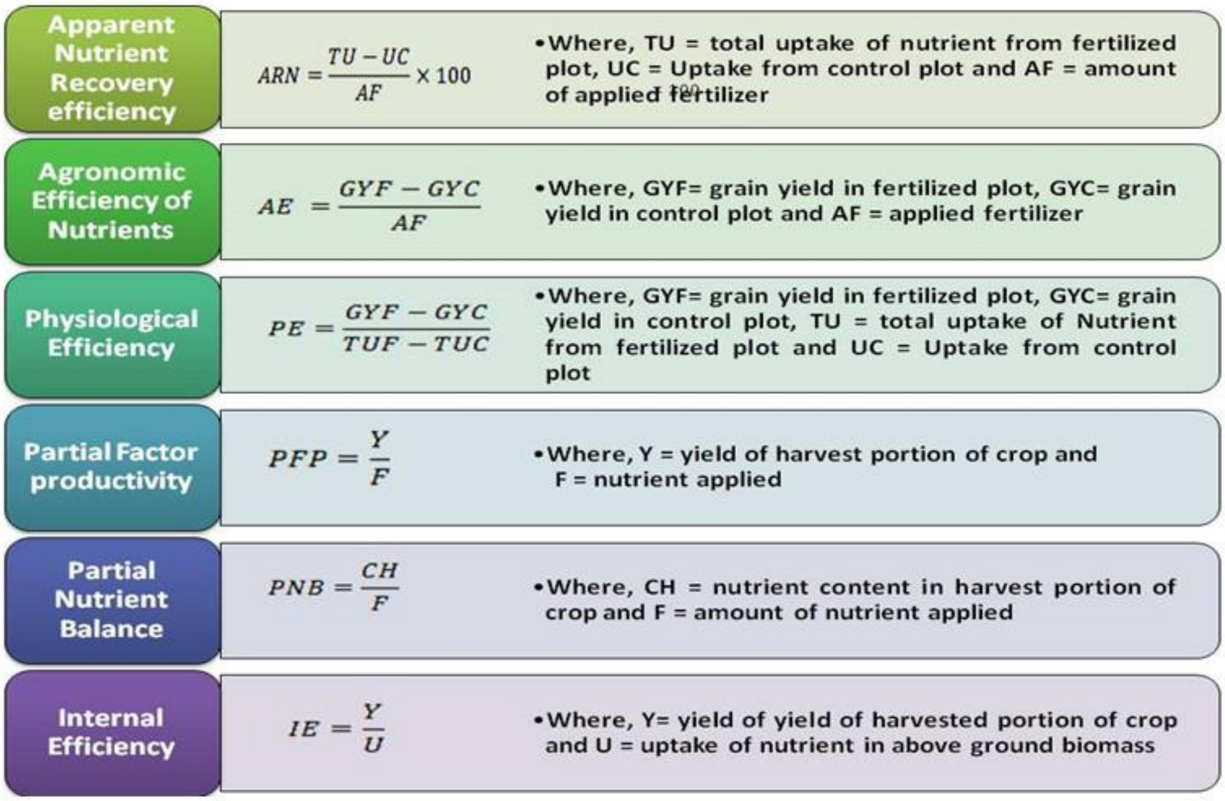

Figure 2 Common nutrient use efficiency indices (after Dobermann, 2007)

NUE Application and Benchmarks

In most cases, it is helpful to use more than one NUE term when evaluating any management practice, allowing for a better understanding and quantification of crop responses to the applied nutrients. Different indicators should be used simultaneously. The lowest fertilizer rates under consideration-rates linked to high PNB-often yielded the highest AE. Genetic modifications, such as the recent discovery of a Phosphorus Starvation Tolerance gene that helps rice to access more soil P (IRRI, 2012), will increase PFP and P removal during crop harvest. Such a development has great short-term value to farmers and may allow the system to operate at a lower level of soil P. However, if P use is less than the enhanced removal level, soil P depletion occurs (PNB is greater than 1). Therefore, even with such genetic changes, an appropriate PNB must be obtained for system sustainability. Although individual NUE terms can be used to describe the efficiency of fertilizer application, a complete analysis of nutrient management should include other NUE terms such as grain yield, fertilizer rates, and native soil fertility (Olk et al., 1999). For example, under low soil P availability, the AE for P could be very high with low P rates; however, the PNB for P under this condition could be well above 1, depleting already low soil P reserves. In this case, a low P rate with high AE for P, although a better practice than no P application, would not be considered the best management practice (BMP).

This section highlights the wide range of significant NUE metrics and trends as well as the main influencing variables. Improvements in nutrient stewardship can be facilitated by identifying relevant measures of NUE for the scale of interest, collecting data for these measures, and establishing benchmarks for evaluating the collected data. Benchmarks are best set locally within the appropriate cropping system, soil, climate, and management context and with full knowledge of how NUE measures are being calculated. As indicated in Figure 3, global fertilizer NPK consumption in crops has increased (FAO, 2019).

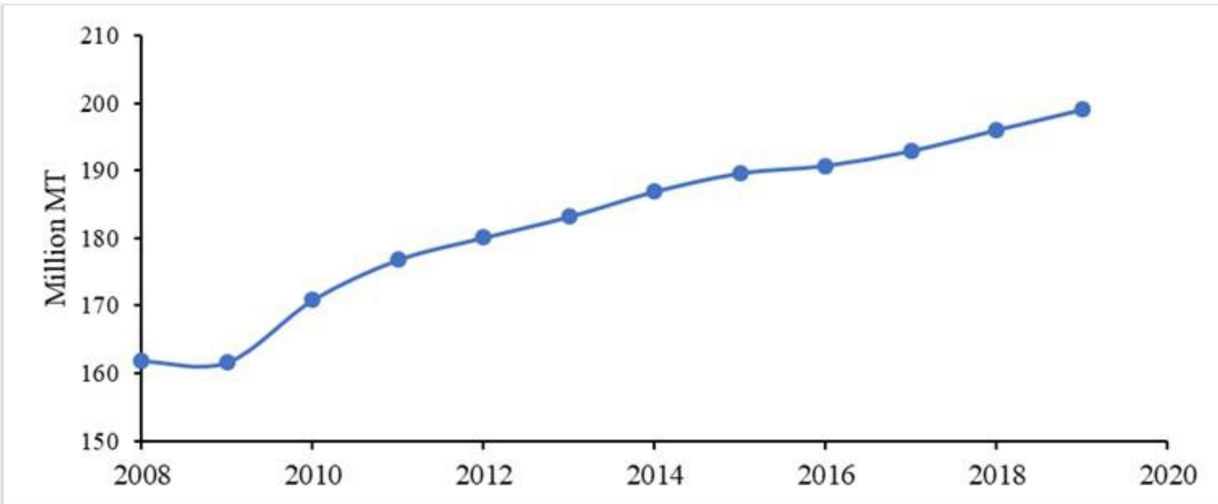

Figure 3. ***Global nutrients (N+P +K) consumption*** *(Source: FAO, 2019)*

Technological Innovations and Best Management Practices

Nanofertilizers

Nanofertilizers are nutrient fertilizers composed, in whole or part, of nanostructured 83 formulations that can be delivered to plants, allowing efficient uptake or slow release of ingredients. Conventional bulk fertilizers have low plant uptake efficiencies; thus, larger amounts are required. Two major challenges of low nutrient uptake efficiency for nitrogen- and phosphorus-based fertilizers are the rapid changes in chemical forms that the plants do not take up and runoff, leaching, or atmospheric losses. The resultant effects are the emission of harmful greenhouse gases, such as certain oxides of nitrogen, and eutrophication, with negative outcomes for soil and environmental health (Dimkpa et al., 2017). Therefore, it is important to develop smart fertilizers that are readily taken up by plants. Consequently, scientists are working hard to develop a variety of metal and metal oxide nanoparticles for use in plant science and agriculture. Because nanoscale particles are smaller in dimension than bulk particles, plants can absorb them with various dynamics compared to bulk particles or ionic salts, which presents an added advantage (Subbaiah et al., 2016). Kumar et al. (2021) reported that the highest grain yield of wheat was 4.8 t/ha with an additional increase of 425 ha^{-1} over FFP, giving a 9.76% increase was found under treatment 50% N-FFP with 2 sprays of nano-urea at active tillering and panicle initiation stage. Azam et al. (2022) found that foliar application of Nano fertilizers with different concentrations increased the plant growth, photosynthetic pigments and antioxidant activity by 59.28, 48.19% and 52.91%, respectively, in maize. The environmental health and safety aspects of nanotechnology should also be considered, and it is important to determine the toxicity and biocompatibility of nanofertilizers (Babu et al., 2022).

The 4Rs of fertilizer management

The fertilizer industry supports the application of nutrients at the right rate, time, and place as a best management practice (BMP) to achieve optimum nutrient efficiency (known as 4Rs).

Right rate: Most crops are location- and season-specific, depending on cultivar, management practices, climate, etc.. Therefore, it is critical that realistic yield goals are established and that nutrients are applied to meet the target yield. Over- or under-application results in reduced nutrient-use efficiency or losses in yield and crop quality. Soil testing remains one of the most powerful tools available for determining the nutrient-supplying capacity of the soil, but to be useful for making appropriate fertilizer recommendations good calibration data is also necessary. Unfortunately, soil testing is not available in all regions of the world because reliable laboratories using methodologies appropriate to local soils and crops are inaccessible or calibration data relevant to current cropping systems and yields are lacking. Other techniques, such as omission of plots, are useful for determining the amount of fertilizer required to attain a yield target (Witt & Doberman, 2002).
This strategy ensures that yield is not restricted by the lack of additional nutrients by applying N, P, and K at sufficiently high rates. Plots with infinite NPK are used to calculate the target yield. To obtain a nutrient-limited yield, one nutrient was removed from each plot. For instance, an N omission plot receives sufficient P and K fertilizers to guarantee that these nutrients do not restrict output, but there is no N fertilizer (Terry, 2008). The gap between the crop's need for nitrogen and the natural supply of the element, which must be filled by fertilizers, results in a difference in grain production between a completely fertilized plot and an N omission plot. The removal of nutrients from crops is an important consideration. Unless nutrients are removed from the harvested grain and crop residues are replaced, soil fertility is depleted.

Right time: Greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, particularly for N (Vijay et al., 2017). It is well known that dividing N treatments over the growing season, as opposed to applying a large amount all at once before planting, improves the N consumption efficiency (Cassman et al., 2002; Giller et al., 2004). Tissue testing is a well-known method used to assess the N status of growing crops; however, other diagnostic tools are available. Chlorophyll meters have proven useful in fine-tuning in-season N management (Francis & Piekielek, 1999), and leaf color charts have been highly successful in guiding split N applications in rice and maize production in Asia (Witt et al., 2005). Precision farming technologies have been introduced and are now commercialized. On-the-go N sensors can be coupled with variable-rate fertilizer applicators to automatically correct crop N deficiencies on a site-specific basis.
Another approach to synchronize the release of N from fertilizers with crop needs is the use of N stabilizers and controlled-release fertilizers (Addisu, 2022). Nitrogen stabilizers (e.g., nitrapyrin (ClC5H3NCCl3), DCD [dicyandiamide] DCD), [n-butylthiophosphoric triamide] NBPT)) inhibit nitrification and urease activity, thereby slowing the conversion of the fertilizer to nitrate (Havlin et al., 2005). When soil and environmental conditions are favorable for nitrate loss, treatment with a stabilizer often increases the N fertilizer efficiency. Controlled-release fertilizers can be grouped into low-solubility and water-soluble compounds.
Most slow-release fertilizers are more expensive than water-soluble N fertilizers and have traditionally been used for high-value horticultural crops and turfgrass. However, technological improvements have reduced manufacturing costs and controlled-release fertilizers are available for use in corn, wheat, and other commodity grains (Blaylock et al., 2005). The most promising for widespread agricultural use are polymer-coated products,

which can be designed to release nutrients in a controlled manner (Addisu, 2022). Nutrient release rates are controlled by manipulating the properties of the polymer coating, and are generally predictable when the average temperature and moisture conditions can be estimated.

Right place: The application method has always been critical in ensuring that fertilizer nutrients are used efficiently. Determining the correct placement is as important as determining the correct application rate. Numerous placements are available, but most generally involve surface or subsurface applications before or after planting. Before planting, nutrients can be broadcast (i.e., applied uniformly on the soil surface and may or may not be incorporated), applied as a band on the surface, or applied as a subsurface band, usually 5–20 cm deep. When applied at planting, nutrients can be applied to the seed, below the seed, or below and on the side of the seed. After planting, the application is usually restricted to N, and the placement can be either a top dressing or subsurface side dress. In general, nutrient recovery efficiency tends to be higher with banded applications because less contact with the soil reduces the opportunity for nutrient loss owing to leaching or fixation reactions. Placement decisions depend on the crop and soil conditions, which interact to influence nutrient uptake and availability.

Plant nutrients rarely function independently. Interactions between nutrients are important because a deficiency in one restricts the uptake and use of the other. Numerous studies have demonstrated that the interaction between N and other nutrients, primarily P and K, affects crop yields and N efficiency. For example, data from a large number of multi-location on-farm field experiments conducted in India have shown the importance of balanced fertilization in increasing crop yield and improving N efficiency. Adequate and balanced application of fertilizer nutrients is one of the most common practices for improving the efficiency of N fertilizer, and is equally effective in both developing and developed countries. In a recent review based on 241 site-years of experiments in China, India, and North America, balanced fertilization with N, P, and K increased first-year recoveries by an average of 54% compared with a recovery of only 21% when N was applied alone (Fixen et al., 2005).

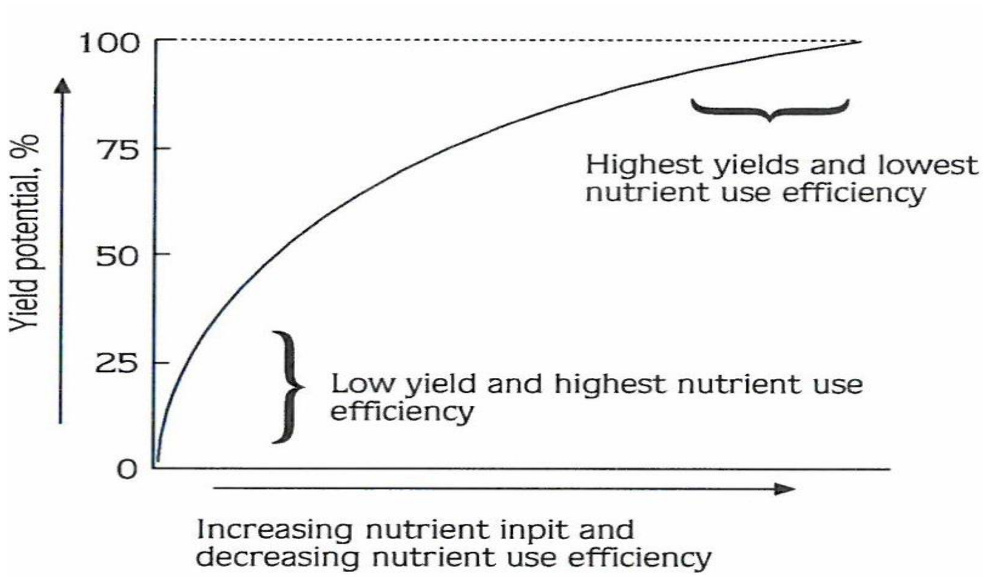

Figure 4 Relationship between yield response and nutrient use efficiency (adapted from Dibb, 2000).

Improving nutrient efficiency is an appropriate goal for all involved in agriculture, and the fertilizer industry, with the help of scientists and agronomists, is helping farmers work towards that end. However, their effectiveness cannot be sacrificed for their efficient use. Simplifying the process of sacrificing yield to obtain far better nutrient efficiency will not benefit the environment or the farmers economically. The relationship between yield, nutrient efficiency, and the environment was described by Dibb (2000) using a theoretical example. For a typical yield response curve, the lower part of the curve is characterized by very low yields because few nutrients are available or applied with very high efficiency (Figure 4). However, efficiency does not necessarily indicate effectiveness. Because a small amount of applied nutrients might result in a substantial yield response, nutrient utilization efficiency is high at low yield levels. Nutrient usage efficiency can be attained in the bottom portion of the yield curve if it is the only objective (George, 2014). However, poor crop growth would result in fewer surface residues to shield the land from wind and water erosion, and less root growth to increase soil organic matter, which would lead to serious environmental problems. Yields grow, albeit more slowly, as you go up the response curve, whereas nutrient-usage efficiency usually decreases.

However, the BMPs used (*i.e.*, appropriate rate, right time, right site, improved balance in nutrient inputs, etc.), along with soil and climate conditions, determine how much of a drop occurs. Fixen (2006) provided an additional explanation for the relationship between efficiency and effectiveness when he proposed that the value of increasing nutrient use efficiency depends on the effectiveness of meeting nutrient use objectives, such as providing the crop with the least amount of nutrients at a reasonable cost, reducing nutrient losses from the field, and contributing to system sustainability through soil fertility or other soil quality components, as presented in Table 1.

Table 1. NPK nutrient requirements for major cereal crops

Crop	N Requirement (kg/ha)	P Requirement (kg/ha)	K Requirement (kg/ha)	Location	References
Wheat	250	150	150	China	Ali et al. (2020)
Maize	49-61	19-23	46-57	Ethiopia	Workneh (2021)
Rice	125	62.5	62.5	India	Prakash (2021)
Sugarcane	281	140	275	Pakistan	Kandhro et al. (2021)
Barley	60	30	20	India	Hansram (2017)

Breeding for Nutrient Use Efficiency

Breeding for improved NTUE will be influenced in part by how NTUE is defined, because it will affect the screening method used, including the measurements that need to be taken, whether fertilizer treatments need to be imposed, and the selection of sites for assessment. More importantly, the type of germplasm that is developed can differ depending on the definition of NTUE used to guide the selection (Glenn, 2014). The problem associated with the definition of NTUE inbreeding for improved nutrient efficiency has been recognized for some time (Blair, 1993; Gourley et al., 1994), although it is far from complete.

One commonly used definition is that proposed by Moll et al. (1982), which was originally used for N use efficiency (NUE) but was subsequently extended to other nutrients (Ortiz-Monasterio et al., 2001). It is defined as the yield per unit of nutrient supplied and has two components: the ability to extract nutrients from the soil (uptake efficiency) and the ability to convert the nutrients absorbed by the crop into grain (utilization or physiological efficiency). While plants derive their nutrients from soil and fertilizer, nutrient supply is often considered to be the nutrients supplied as fertilizer; thus, NTUE is often the yield per unit of fertilizer applied. A problem with using this definition to identify more efficient genotypes is that one essentially selects yield potential. If it is used to assess NTUE of a diverse range of genetic material, lower-yielding varieties (such as landraces or old varieties) will have low NTUE even if they possess traits that may enhance nutrient uptake and use. Differences in the yield potential confounded the assessment of efficiency when this definition was used.

Precision Farming

Precision farming is an information- and technology-based farm input management system that aims to use technologies and principles to identify, analyze, and manage the spatial and temporal variability associated with all aspects of agricultural production within fields to maximize profitability and sustainability, enhance crop performance, protect land resources, and maintain or improve environmental quality (McBratney et al., 2005). Measurement of variability in the field concerning N and the application of the right amount of N at the right time using a variable rate applicator, remote sensing, geographic information systems (GIS), and global positioning system (GPS) technology may act as important information tools for farmers to improve NUE under the specific conditions of each field.

Precision farming tools help provide the requisite resources according to the requirements without excess or deficiency at each point in time during the crop growing season (Cassman, 1999). It is comprehensively used in agriculture for precise analysis of soil, planting, agrochemical application, proper crop monitoring, irrigation, and crop health assessment (Clercq et al., 2018). Soil tests and tissue analysis methods are widely used conventional approaches to determine the nutrient status of the soil; however, the use of precision farming tools such as GIS, drone, satellite imagery, green seeker, Holland Crop Circle, and other related tools were found to be comparatively better than the conventional methods (Sharma & Bali, 2017) and assist in optimizing the use of resources, improving NUE, and reducing environmental problems.

Enhancing Nutrient Cycling and Soil Health

Soil amendment has become a popular and quick way to improve soil quality in recent years. To preserve soil nutrient homeostasis, soil amendments can include sources of carbon (C) as well as other nutrients, including potassium (K), phosphorous (P), and nitrogen (N) (Yanhong et al., 2023; Garbowski et al., 2023). Additionally, soil amendments improve the soil structure and increase water retention to counteract nutrient loss and maintain soil fertility (Zhang et al., 2023). In dry and semiarid locations, the ability of soil amendments to retain more water is especially important for reducing the effects of seasonal drought and high rainfall events caused by climate change (Kuanyan et al., 2022). Furthermore, because the availability of these elements greatly affects microbial diversity and community structure, changes in soil nutrient and moisture levels can have a substantial impact on soil microorganisms. Fungal communities are notably affected by soil moisture conditions, which in turn affect their radial growth, sporulation, germination, and mycelial cord formation (Maryann & Huhta, 2000). However, bacterial populations are affected by changes in soil nutrients, particularly when organic fertilizers are added. This may lead to an increase in the relative abundance of beneficial bacteria (Jiai et al., 2021). The soil nutrient cycle may also be changed by modifying the activity of soil microorganisms (Chao et al., 2024). For example, Anaeromyxobacter and Haliangium facilitate N and P solubilization (Masuda et al., 2020; Wang et al., 2021). The vital roles of these microorganisms in controlling soil nutrient cycling, especially in arid and semi-arid regions, have been overlooked in favor of previous studies that have focused on how soil amendments affect fungi or bacteria in response to changes in the soil environment (Tran et al., 2023; Shiv et al., 2024).

For crops to continue growing healthily, soil nutrient cycling is essential (Prasad et al., 2021). Certain components (such as organic C) can be quickly enriched by soil amendments; thus, additional N must be microbially decomposed to maintain a steady C/N ratio. Additionally, through recycling and decomposition, soil microbes help liberate mineral nutrients from soil additions, increasing their availability for plant uptake, and consequently, soil fertility (Liu et al., 2023). Although fungi may play a more significant role than bacteria in soil nutrient cycling during forest conversion, some studies have found strong correlations between bacterial diversity and soil organic carbon (SOC), total nitrogen (TN), and soil multi-nutrient cycling in sandy ecosystems and coastal wetlands (Liu et al., 2021; Zhang et al., 2022).

Microbes are important entities that give life to the soil and are responsible for soil health, environmental sustainability, and sustaining the life of plants and animals on Earth. It has been said by a renowned microbiologist CR Woese "If we wiped off all the multicellular organisms (plant and animals) from the earth's surface, then it would barely affect the microbial community where the destruction of the microbial community would lead to instant death of all life forms on earth". Healthy soil is characterized by the presence of a diverse range of microorganism populations, including bacteria, fungi, protozoa, viruses, archaea, archaea, cyanobacteria, actinomycetes, and microalgae. Microbes play a major role in nutrient cycling, and thus help in nutrient acquisition and availability. These characteristics have placed microbes into different categories depending on their potential for enhancing nutrient uptake by plants. Plant growth-promoting rhizobacteria are potential biofertilizers that play a significant role in improving nutrient availability through nitrogen fixation, phosphorus solubilization, potassium solubilization, phytohormone production, organic matter decomposition, and iron nutrition through siderophore production (Goswami et al., 2016). An increase in nutrient use efficacy is one of the many beneficial effects of soil microorganisms. Furthermore, plant growth-promoting rhizobacteria (PGPR) are environmentally friendly and can help reduce environmental degradation.

Economic and Environmental Implications

Balanced fertilization ensures the application of appropriate amounts and proportions of nitrogen (N), phosphorus (P), potassium (K) and trace elements based on crop requirements and soil fertility performance. Many countries have been actively promoting and applying this approach. In certain regions, China has conducted experimental research and established demonstrations of the efficient application of trace elements and K fertilizer. Examples include the combination of P and Zn applied to wheat seedlings (Yang et al., 2009), boron and calcium applied to rape (Du, 2003), and N and K applied to potato (Xian et al., 1993). After decades of experimentation and promotion, both the theory and practice of appropriate fertilizer application have been well-established in China. However, because of the great differences in climate, soil fertility, and soil texture, as well as the cultivation of new crop varieties and climate change, it is difficult for farmers to be certain about amounts and proportions, and inappropriate use of fertilizer still occurs. The goal of balanced fertilization is to maximize the yield to meet the growing population's demand for agricultural products. Consequently, the ideal amount of fertilizer is typically chosen based on yield or financial gains (Hui et al., 2015). Crop quality, agricultural sustainability, and environmental issues associated with fertilization have not been fully considered (Zhu & Chen, 2002). Many studies have shown that fertilizer treatments that produce the highest yields tend to result in lower crop quality and greater nutrient losses. Nitrate leaching increases significantly when the nitrogen application rate exceeds 150–180 kg hm^{-2} (Zhu & Chen, 2002; Li et al., 2019). Excessive application of N fertilizer can lead to a significant increase in nitrate-nitrogen content in groundwater (Akbariyeh et al., 2018), and N_2O production increases significantly when the amount of nitrogen applied exceeds 180 kg hm^{-2} (Nan et al., 2016). In recent years, with the improvement in China's economy and living standards and the enhancement of environmental protection, people not only want to consider the yield and economic benefits delivered by fertilizer application but also pay more attention to its relationship with crop quality and the environment. Thus, the determination of appropriate fertilizer application rates for each region and crop should take into account the relationship between crop yield, quality, and environment, and should not trade quality and environment for high yield.

In studies of balanced fertilization, potassium plays a more important role than other elements in improving crop quality and reducing environmental pollution caused by the loss of N and P fertilizers. Many studies have shown that when there is sufficient K, K ions significantly promote the absorption and utilization of N and P by crops in the form of compensation charges (Barnes et al., 1976), improving the utilization rate of N and P fertilizers (Reid et al., 2016), thus reducing pollution. The application of K fertilizer also promotes carbohydrate and N metabolism, thus improving the quality of crop products, for example, by increasing the protein content of grain crops (Gaj et al., 2013), crude fat and palmitic acid content of oil crops (Choon-Hui et al., 2009), starch and sugar content of potatoes and sugar crops (Westermann et al., 1994), and fiber length, strength, and fineness of fiber crops and cotton (Pervez et al., 2004). Despite the above advantages of K fertilizer, the proportion of N, P, and K nutrients applied is still often inappropriate due to the habits of farmers and a lack of guidance regarding K fertilizer. The average ratio of N, P, and K fertilizers used in China is 1:0.43:0.17, which is significantly lower than the world average of 1:0.47:0.37 and 1:0.57:0.55 in developed countries (Gu et al., 2014).

Challenges and Future Directions for NUE of Cereals

Enhancing our understanding of how different sources of nitrogen and their management affect the root systems of crops, along with their implications for aboveground growth, is crucial for the advancement of improved nitrogen fertilizers and management approaches. This understanding can help align soil nitrogen availability with crop nitrogen requirements, leading to enhanced nutrient use efficiency. Likewise, a more intentional consideration of plant physiological mechanisms, encompassing various methods of mineral nutrient uptake, their movement within the plant, and metabolic processes, is essential in the formulation of contemporary fertilizer solutions (Bindraban et al., 2015). Efforts to enhance nutrient-use efficiency play a vital role in achieving sustainable and productive agriculture. Through a combination of traditional practices and innovative technologies, farmers can optimize nutrient uptake, improve yield, and minimize environmental harm. The ongoing challenge lies in translating the research findings into practical and accessible solutions for a diverse range of farming systems.

General Future Directions

- Soil test recommendations should be followed.
- Inclusion of legumes in the rotation cropping system.
- Balanced NPK application with organic manure is key to efficient fertilizer use and sustainable agriculture.

- About 60-70% of K removed by crops is in straw; therefore, crop residue recycling is a good way to replenish soil K.
- Non-monetary inputs,, such as proper tillage, sowing time, seed rate, water and weed management, and proper plant measur,es, increase the efficiency of applied NPK.

Conclusions

Enhancing nutrient efficiency is an admirable objective and a major problem for the fertilizer sector and agriculture as a whole. Increasing the effectiveness of applied nutrients may be achieved using current tools and opportunities. However, we must be careful so that increases in efficiency do not compromise the environment or farmers' capacity to make a living. Farmers, society, and the environment will all profit from the prudent use of fertilizer BMPs, or the right rate, right time, and right place, which aim for both high yields and nutrient efficiency. There has never been more interest in and awareness of increased nutrient-usage efficiency. The fertilizer industry is facing increased pressure to increase nutrient usage efficiency due to the growing public view that crop fertilizers are excessive in the environment, and farmers are worried about rising fertilizer prices and stagnating crop prices. Nonetheless, there are several ways to define efficiency, which can sometimes be misinterpreted. The nutrients collected in the aboveground portion of the plant or the nutrients retrieved across the soil, crop, and root systems are two possible definitions of agronomic efficiency. Because future yield increases, nutrient costs, and crop prices are unknown before the growing season, economic efficiency is the state in which farm revenue is maximized by the appropriate use of nutritional inputs. However, this is not always accomplished or anticipated. The only way to establish environmental efficiency is to research local goals that are susceptible to nutrient influences. Unused nutrients by the crop may end up in the environment, although how susceptible they are to loss depends on the nutrient, soil, climate, and geography. In general, nutrient loss to the environment is only a concern when fertilizers or manures are applied at rates above agronomic needs; therefore, applying nutrients by area and crop-specific rates for cereals, especially primary macronutrients, is best. Moreover, scientists have developed various management approaches to enhance nutrient use efficiency in agriculture, including soil and crop management, integrated soil management, precision agriculture, and root zone fertilization; however, their combined use is more effective.

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RESEARCH ARTICLE

Plant Diversity and Ethno-botanical Assessment of Tehsil Takht Bhai, Mardan, Khyber-Pakhtunkhwa, Pakistan

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Abstract

Ethno-botany is the scientific study of traditional knowledge, and customs of people concerning plants and their medical, religious and other uses. The present study was aimed to gather and document the traditional knowledge and practices of the local inhabitants related to medicinal uses of the plants in the area. To understand the ethno-botanical uses and importance of the plant, a questionnaire survey was conducted to collect quantitative, and qualitative information from randomly selected 138 local inhabitants of the Tehsil Takht Bhai, Mardan. The data were statistically analyzed by using SPSS software. The results reveals that medicinal plants are used for the treatment of various ailments and health issues, the plants were mostly used for diabetic (8.7%). The plants use was also recorded for backache (6.5%), followed by constipation and urinary tract infection (5.6), dry cough (4.3%), abdominal swelling and hemorrhoids (3.6%), and dysentery (3.5%). We also report on the people perception parts uses. According to report shows that the most commonly used part was fruits (24.6%), followed by bark (15.2%), whole plant (5.1%), roots (3.6%), stems (3.6%), flowers (1.4%), and seeds (1.4%). However, plant recipes were recorded from the local respondents, mostly reported recipe is powder form of plants (29.7%), followed by crushing (28.3%), directly use (15.2%), chewing (11.6%), boiling with water (7.2%), decoction (5.1%), boiling with tea (1.4%) etc. We conclude from the survey that the species population has been frequently used for various medicinal purposes, and the local inhabitants have more knowledge about the medicinal plant species. So, it is important the uncontrolled use of the plant as ethno-medicinal drug due to its great economic value. However, it is recommended that further investigation on local flora is necessary into their possible medicinal uses and proper documentation of the knowledge for young generation and researchers.

Keywords: Ethno-botany; Medicinal plants; Questionnaire method; Tehsil Takht Bhai; Mardan; Pakistan

Introduction

Plants are the primary producers and have the ability to synthesize their own food material via photosynthesis process and transfer minerals, gasses and water to other living things. Along with food plants also supply dyes, building material, fiber, landscape, cosmetics and medicines to human being as well as control air pollutions. Plants play important role in our lives, because it aid in the recycling of various functional nutrients, and provide us herbal medicines (Ajaib *et al.,* 2015; Ajaib *et al.*, 2013; Ajaib *et al.,* 2014). Ethno-botanical studies as the relationship between plants and people or the dynamic relationships between human and plants in a common habitat (Barnes *et al.,* 2003). The studies of ethno-botany focused on processing of our understanding of plant-biodiversity (Prada *et al.*, 2018). In order to validate how plants are used for various religious purposes, housing, clothing, medicine, food, and others ethnobotanical studies have a specific geographical, and culture area (Ajaib *et al.,* 2013; Shuaib *et al.,* 2014; Ullah *et al.,* 2022). The ethnobotanical research helps to develop community priorities to translate local values into efficient resource management, preservation of cultural knowledge, and biological diversity protection (Ngunde *et al.*, 2022). The ethnobotanical studies are needed to locate vital plant species unique to a specific region, mainly when looking for primitive plants. The research studies have documented traditional knowledge, and found several essential plant resources in modern medicines. The livelihoods of under-developed countries worldwide depend on medicinal plants and about 258,650 plant species were exist and above 10% of them are used medicinally (Shopo *et al.,* 2022).

The ancient practice of using therapeutic plants has been the precursor to modern medicine, with many contemporary treatments drawing on the wisdom of traditional herbal remedies. The pharmaceutical industries have trusted deeply on plant derived compounds, and this trend continues to the present day. Besides, the authors found that the important organizations, authors and nations have studied this subject, and their expansion with the passage of time have been recognized. The contacts between the nations, authors and new research has been observed via the finding of local communities. The study has been observed to have shrunk from the previous period comprised unclassified conventional medicines, drugs, cancer, anti-inflammation and in vivo studies of anti-diabetics in animals. Additionally, the authors made the case that cultivation or domestication of plant species with his established potential is less of a priority in global research trends instead of research for active compounds or novel drugs (Salmerón-Manzano *et al.*, 2020; Zulfiqar *et al.*, 2022).

Moreover, the ethno-botanists can play an important role in reintroducing and saving this precious knowledge that is rapidly being lost by the local populations. Then, it must be possibly maintained and documented the unwritten folk knowledge of plant resources for the recent increase civilization of the tribal. There are several people involved in trading of important medicinal plants on local, regional and global level, especially in rural areas people used native medicinal plants for the treatment of various diseases (Ali *et al.,* 2017; Kumar *et al.,* 2022). The ethnobotanical practices were passed down from generation to generation by the people of different areas and casts (Lev & Amar, 2000). According to report a wide range of people used medicinal plants for the treatment of various human diseases and people belief that medicinal-plants were the primary health care system of the people inhabiting in rural area i.e., Gokwe South District (Achour *et al.*, 2022).

In Pakistan, the ethno-botanical practices were commercially well established and the written record were save from last new decades, and about 85% Pakistani people were dependent on indigenous plants. In Baluchistan province the area of Musakhel and Barkhan flora were the focus of several ethnobotanical investigations. The ethno-botanical knowledge has a strong connection between plants and people culture, meanwhile it is known as the multidisciplinary approach that comprises various beautiful or fascinating characters, records, tradition, literature, culture and believes of plants (Ali *et al.*, 2017; Khan *et al.*, 2021). The finding of the present ethnobotanical studies were highlight that how local people use traditional ethnobotanical knowledge to treat human related disorders as compare Pakistan with other developing countries (Jima & Megersa, 2018). The main aim of the study was to investigate the ethno-botanical survey of local medicinal plants and to identify the local names, botanical names, folk uses, parts uses, and method of uses in Tehsil Takht Bhai, Mardan.

Methodology

Data Collection

Frequent field trips were made to evaluate the species status from the residents of Tehsil Takht Bhai, Mardan. The local respondents were classified based on age groups. The survay was carried out during January 2022 to September 2022. A total of 138 people were interviewed and the interview were conducted in local language Pashto. The respondents were asked about the plant local name, botanical name, folk uses, parts used, and recipes of the plants (Table. 1). All the respondents were local inhabitants of Takht Bhai, Mardan. During various field trips the plants specimen i.e., plant branches, leavers, flowers, fruits and seeds were collected, documented, pressed and shade dried as well. We have a proper field note book to collect information related to plant species i.e., locality, sub-locality, leaves, flower colours, fruit types, uses, distribution and their influence among local flora. However, we also used canva camera for pictures record of the local plant species. Additionally, the shade dried fresh plant specimen were prepared by using some tools to press the plants for future use such as press straps, clippers, hand lens, newspapers, and ethyl-alcohol. The collated plant specimen were identified by using the online plant list (http://www.theplantlist.org) and flora of Pakistan (http://www.tropicos.org/Project/Pakistan) (Table. 1).

Study Area

The current study was carried out in a rural area Tehsil Takht Bhai, district Mardan, Khyber Pakhtunkhwa, Pakistan. The area were located about 15 kilometers to the north side of Mardan city. The area lies on 71°56′48 E latitude and 34°17′ 10 N longitude with elevation ranging from 1120 to 1430 feet above sea level. The mean annual temperature of the area ranges from 0.5 to 43.5 °C. The mean annual precipitation is rarely exceeding from 200m. The district is surrounded by Distrct Buner on North, District Nowshera on South, District Sawabi on East, and District Charsadda on west (Fig. 1; Khan, 2018; Ilyas *et al.*, 2013; Shah *et al.* 2014; Khan & Badshah, 2019; Khan & Ullah, 2019, Khan *et al.* 2020; Ullah & Asad, 2020, Parveen *et al.,* 2021).

Research Questionnaire

The ethnobotanical information of Tehsil Takht Bhai, district Mardan was collected from the local respondents via a questionnaire designed in MS Word (Parveen *et al.,* 2021). The questionarre comprises relevent questions i.e., peronal information of the respondents (name, age, occupation, village etc), plant name both local and botancal, plant uses, parts used, and method of use. The respone information of local interviwers were accurate and precise (Tembo *et al.*, 2021).

Statistical analysis

For statistical analysis of the collected data, firstly the data were organized and managed in MS office (MS-XL), and then a frequency distribution test or chi square test were used to statistically analyze the data by using SPSS version 22.0 (Navia *et al.*, 2022).

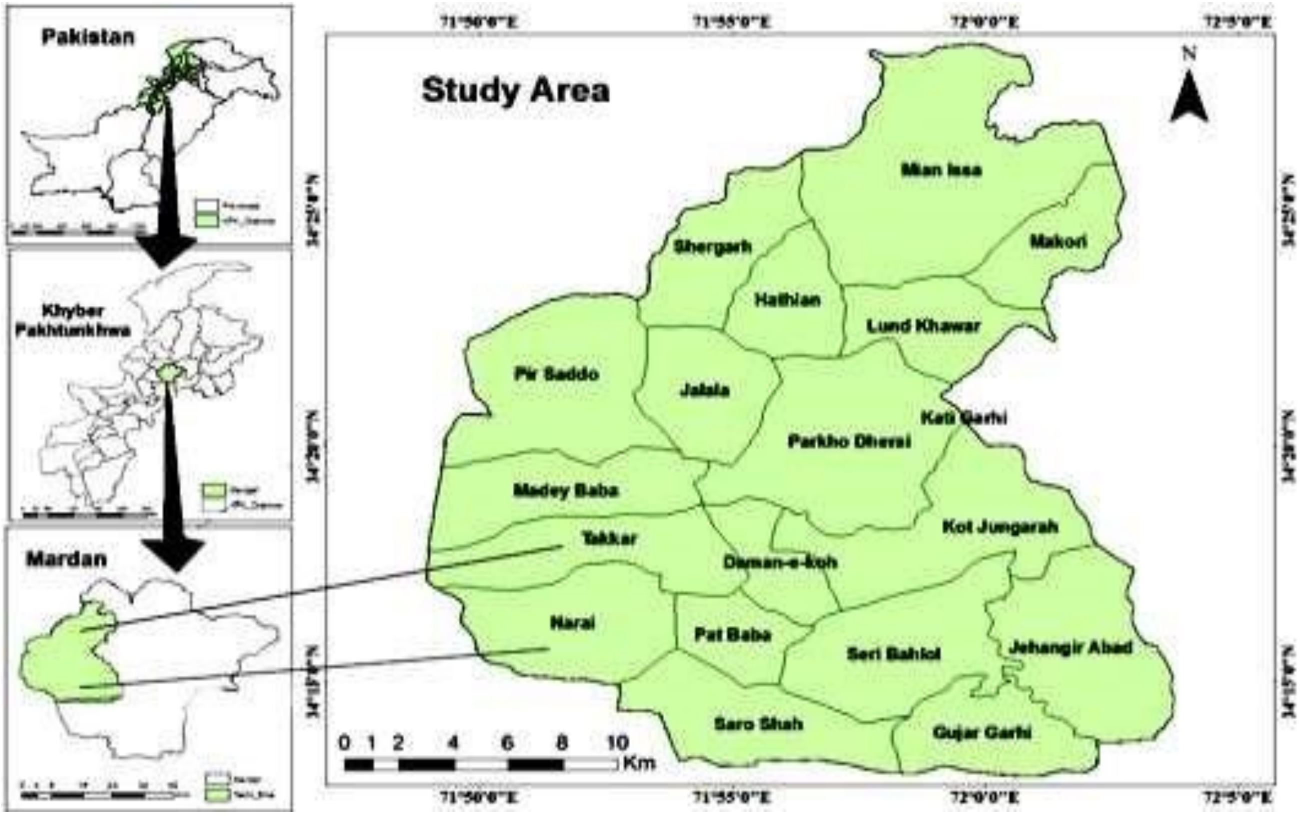

Fig. 1 Study area map of Tehsil Takht Bhai, Distrisct Mardan, Khyber Pakhtunkhwa, Pakistan.

Results

The study area is well-known for its diverse plant biodiversity, and ancient ethno-botanical knowledge. The current study focuses on 56 plant species belongs to 42 plant families, and the most commonly known plants are *Prunus domestica, Prunus armeniaca, Punica granatum, Psidium guajava, Ficus carica, Fragaria nubicola, Ricinus communis, Periploca aphylla, Polygonum aviculare, decne, Chenopodium albal, Datura stramonium, Mentha longifolia, Rheum australe, Juglans regia, Phoenix dactylifera, Rubus fruticosus, Foeniculum vulgarel, Vachellia, musa, Paeonia emodi, Papaver somniferum, Vinceloxicum, Malus pumila, Euphorbia helioscopia, Solanum surattense, Citrus limon, Citrus sinensis, Senegalia modesta, Mentha arvensis, Malva neglectar*, *Melia azedarach, Phoenix dactylifera, Chenopodium album, Nasturtium officinale, Trifolium repens, Calotropis procera, Rumex hastatus, Oxlis coniculata, Morus olba, Diospyros lotus,* and *Dicliptera bupleuroides nees* etc. However, the most widely used parts of plants were fruits, leaves, stems and roots. The plants parts are used for various purposes i.e., as a fuel for combustion, as a medicines for various diseases and as a building material. Meanwhile, the local inhabitants used these plants for many diseases i.e., fever, cough, diarrhea and skin disorders etc (Table. 1). The study offers essential knowledge for plant resource conservation and sustainable use.

Table. 1 Plants local name, botanical name, medicinal folk uses, parts used and method of uses of Tehsil Takht Bhai, Mardan.

S. No	Botanical Name	Local Name	Disorders	Parts Used	Method of Uses
1	*Prunus domestica*	Alocha	Back pain	Bark	Direct
2	*Diospyros kaki*	Amlook	Diarrhea	Fruits	Direct
3	*Psidium guajava*	Amrood	Diarrhea	Fruits	Direct
4	*Punica granatum*	Annar	Anemia	Fruits	Crushing
5	*Ficus carica*	Anzar	Peptic ulcer	Fruits	Direct
6	*Ricinus communis*	Arhand	Pimple /boil	Leaves	Direct
7	*Fagonia cretica*	Azghaky	Jaundice	Fruits	Crushing
8	*Polygonum aviculare*	Bandakai	Dysentery	Whole plant	Crushing
9	*Periploca aphylla*	Barara	Constipation	Leaves	Chewing
10	*Chenopodium album*	Chalwai	Laxative	Leaves	Boiling
11	*Mentha longifolia*	Ellanay	Jaundice, U.T. I	Leaves	Powder
12	Juglans regia	Ghoz	Bone injuries	Leaves	Crushing
13	*Mirabilis jalapa*	Gulabasi	Inflammation	Leaves	Direct
14	*Prunus armeniaca*	Hoobani	Respiratory	Fruits	Crushing
15	*Ficus carica*	Inzar	Cough and cold	Fruits	Crushing
16	*Syzygium cumini*	Jaman	Diabatic	Fruit	Direct
17	*Foeniculum vulgare*	Kaga	Diarrhea	Leaves	Decoction
18	*Rubus fruticosus*	Toor Tooth	Diarrhea	Leaves	Crushing
19	*Vachellia nilotica*	Kharboty	Scabies	Leaves	Direct
20	*Musa Paradisiaca*	Kilaa	Diarrhea	Fruits	Direct
21	*Papaver somniferum*	Kooknar	Dry Cough	Bark	Black tea
22	*Eucalyptus globulus*	Lachi Pana	Diarrhea	Leaves	Powder
23	*Paeonia emodi*	Mamekh	Back pain	Roots	Boiling
24	*Euphorbia Helioscopia*	Mandaro	Laxative, Toothache	Steam	Powder

25	*Malus pumila*	Manrda	Bone health	Fruits	Direct
26	*Solanum surattense*	Marraghonary	Toothache	Fruit	Chewing
27	*Citrus sinensis*	Naranj	Vomiting	Leaves	Boiling
28	*Citrus limon*	Nembo	Kidney stone	Fruits	Direct
29	*Spinacia oleracea*	Palak	Urinary calculi	Leaves	Boiling
30	*Senegalia modesta*	Palusa	Backache	Bark	Powder
31	*Malva neglecta*	Panerak	UTI	Leaves	Boiling
32	*Mentha arvensis*	Pasima	Peptic ulcer	Leaves	Chewing
33	*Mentha arvensis*	Podina	Vomiting	Leaves	Chewing
34	*Phoenix dactylifera*	Qajora	Oligo Spermia	Fruits	Direct
35	*Chenopodium album*	Sarmay	peptic ulcer	Whole plant	Direct
36	*Rumex, dentalus*	Shalkhay	Wound healing	Whole plant	Decoction
37	*Melia azedarach*	Shandai	Abdominal swelling	Leaves	Powder
38	*Trifolium repens*	Shawtal	Fevers	Leaves	Boiling
39	*Taraxacum officinale*	Shodasi	Constipation	Leaves	Decoction
40	*Gymnosporia royleana (Wall) Lawson*	Soor azgy	Heartburn	Leaves	Crushing
41	*Calotropis procera*	Spalmai	Hemorrhoids	Leaves	Crushing
42	*Morus olba*	Spen toot	Insomnia	Fruits	Chewing
43	*Fragaria nubicola*	Strawberry	CVS	Fruits	Direct
44	Nasturtium officinale	Tarmera	Backache	Whole Plant	Boiling
45	*Diospyros lotus*	Toor amlook	Dysentery	Fruits	Direct
46	*Rubus fruticosus*	Toor Tooth	Anti-diabatic	Fruits	Direct
47	*Melia azedarach*	Tora shandy	Anti-diabatic	Fruit	Direct
48	*Oxlis coniculata*	Triwaky	Peptic Ulcer	Leaves	Direct
49	*Dicliptera bupleuroides*	Tura panra	Peptic Ulcer	Whole plant	Boiling
50	*Cynanchum vinceloxicum*	Zangali toot	Diarrhea	Fruit	Direct

51	*Vachellia nilotica*	Kikar	Diabatic	Bark	Boiling
52	*Capsicum annuum*	Marchaky	Fever	Fruit	Powder
53	*Foeniculum vulgare*	Kagha	Heart burn	Seeds	Direct
54	*Coriandrum sativum*	Danya	Diabetic	Leaves	Crushing
55	*Prunus persica*	Shaltalo	Diabetic	Leaves	Crushing
56	*Citrus sinensis*	Manta	Cough and cold	Fruit	Direct

Classification of respondents based on age groups

The current study reports ethno-botanical knowledge from people of different ages. The local respondent's age ranges from 46 to 90 years old. The age group with the highest prevalence, with a frequency of 13 and a percentage of (9.4%), is 60. The second most predominant age-group is 70, with a frequency of 12, and a percentage of (8.7%). However, the age-groups with the lowest frequency i.e., 1 and percentage less than 1% is 46, 47, 56, 67, 77, and 82 years old respectively (Fig. 2).

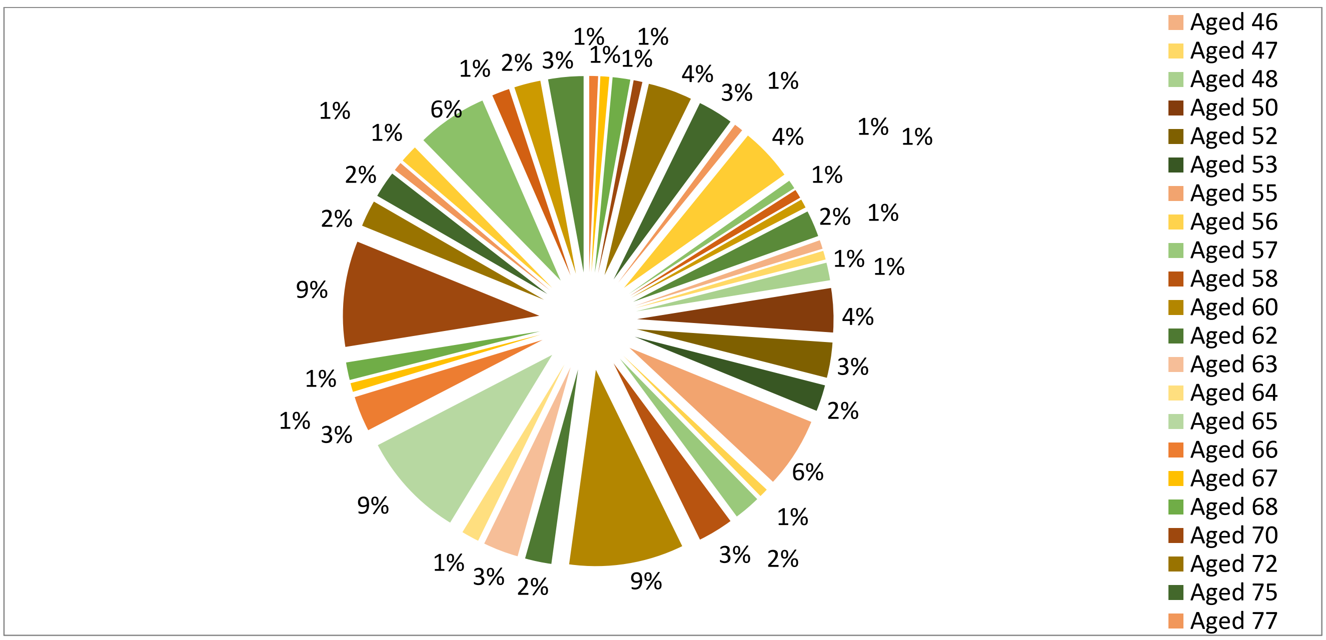

Fig. 2 Classification of local respondents based on age groups

Classification of respondent based on gender

The local interviewer including both male and female i.e., 5 (3.6%) of the 138 respondents were female, while 133 (96.4%) were male (Fig. 3).

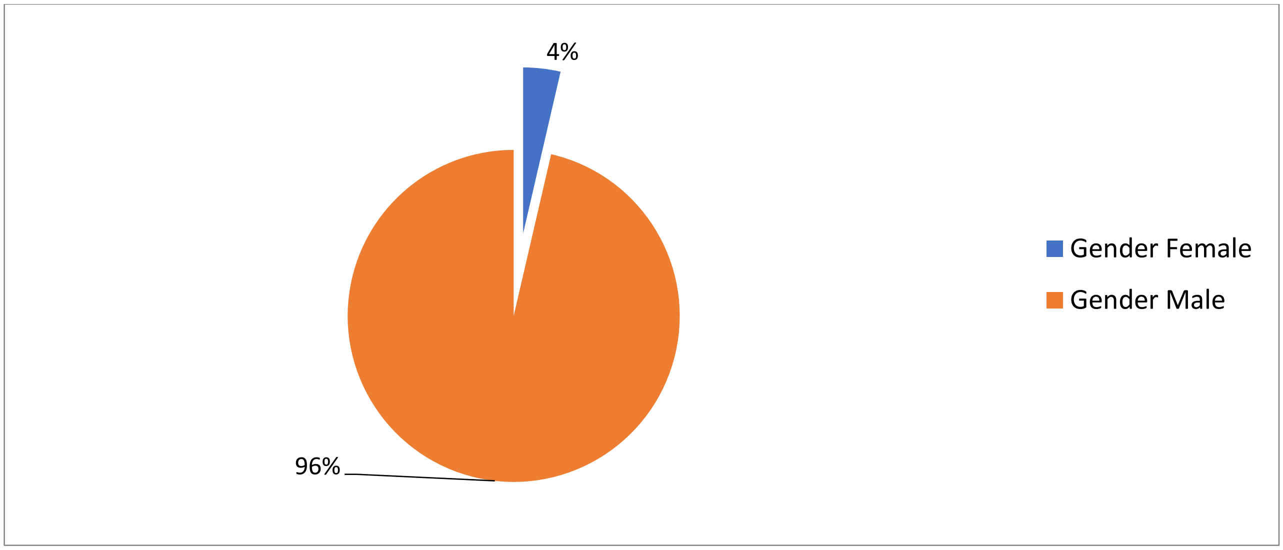

Fig. 3 Classification of local respondents based on gender i.e., male and female

Classification of respondents based on occupation

The distribution of respondents based on occupation are (45.6%) of the inhabitants were local farmers followed by shopkeepers and teachers (10.9%), entrepreneurs (7.2%), and drivers (5.8%). The local respondents also contain workers of other profession i.e., police (5.1%), medical storekeeper (3.6%), students (2.2%), and teachers (10.9%) etc. However, (5.8%) of the respondents having no occupation (Table. 2 and Fig. 4).

Table. 2 Classification of respondents based on occupation.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Business	10	7.2	7.2	7.2
	Driver	8	5.8	5.8	13.0
	Farmers	36	45.6	45.6	81.9
	Hakim	1	0.7	.7	59.4
	Labour	1	0.7	.7	60.1
	Medical Storekeeper	5	3.6	3.6	63.8
	Nill	8	5.8	5.8	69.6
	Police	7	5.1	5.1	74.6
	Shopkeeper	15	10.9	10.9	85.5
	Student	3	2.2	2.2	87.7
	Subadar	1	0.7	.7	88.4
	Teacher	15	10.9	10.9	99.3
	Veterinary	1	.7	.7	100.0
	Total	138	100.0	100.0	

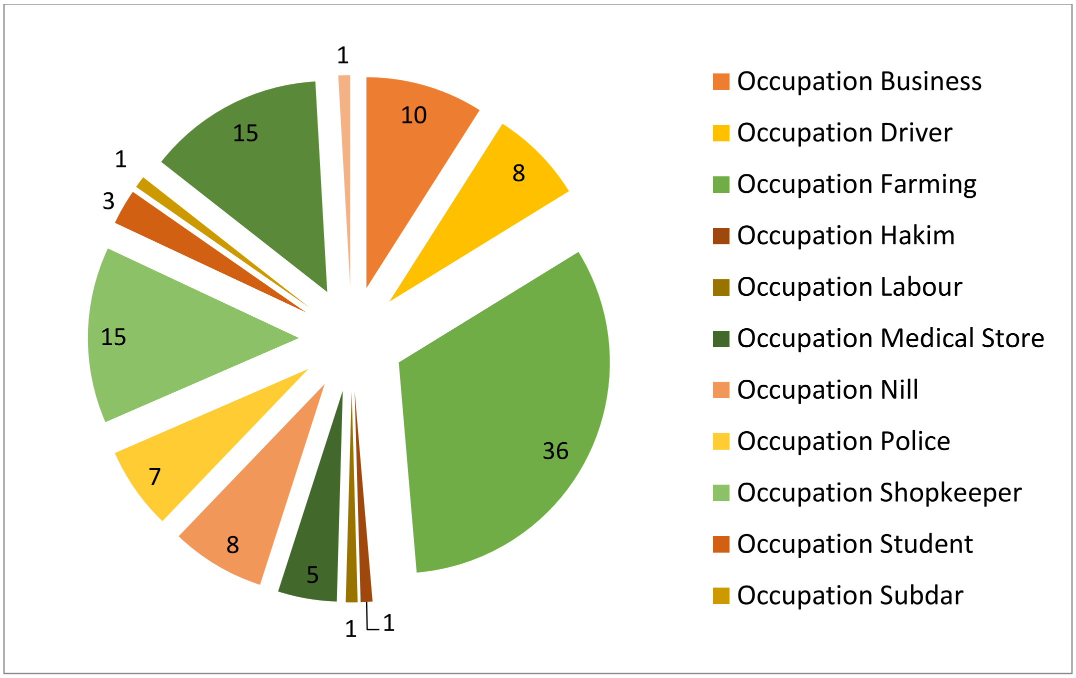

Fig. 4 Classification of local respondents based on various occupations.

Classification of respondents based on education level

The local interviewers were also classified based on education level i.e., (24.0%) of respondents were BA degree holders, followed by matric level (22.5%), middle level (17.4%), B. Sc level (10.1%), primary level (9.1%), FA level (7.2%), degree level (2.3%), and only (1.2%) is postgraduate level person. The result shows that majority of ethno-botanical information is provided by the respondents having low knowledge of modern techniques (Fig. 5).

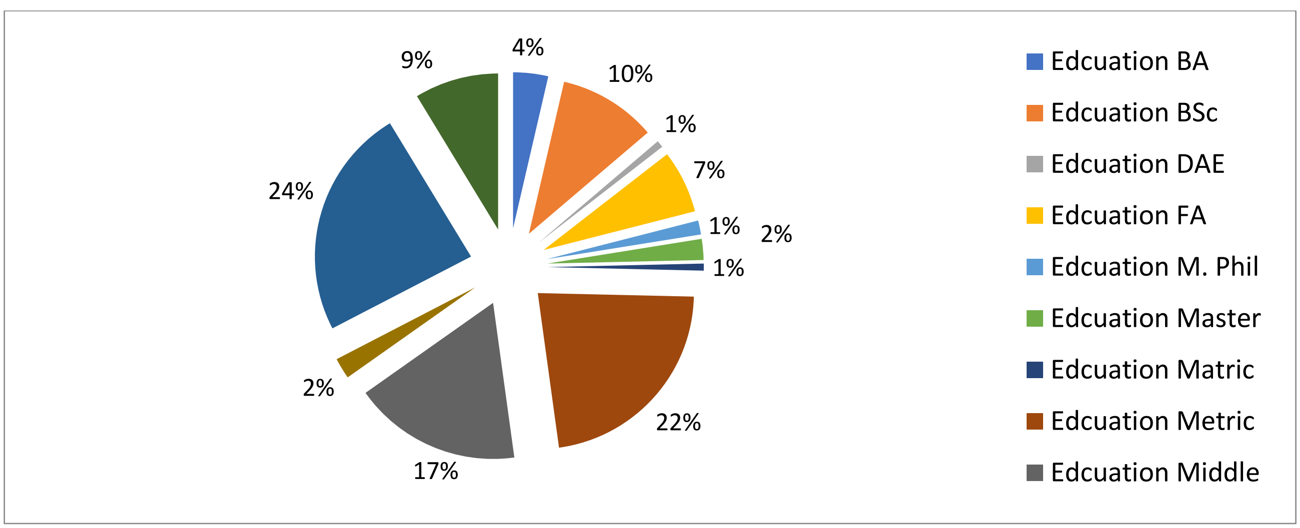

Fig. 5 Shows groups of respondents based on education level.

Medicinal uses of local plant diversity in Takht Bhai Mardan

The medicinal uses of the local plant diversity shows that it is used most abundantly as diabetic with (8.7%), backache with (6.5 %), constipation and urinary tract infection with (5.6 %), followed by dry cough with (4.3%), abdominal swelling and hemorrhoids with (3.6%), dysentery with (3.5%), gonorrhea, oligospermia, laxative, stomach discomfort, and scabies with (2.9%), peptic ulcer with and duodenal ulcer (2.8%), chicken fox with (2.5%), anemia and vomiting with (2.2%), burning wound, appetizers, CVS disease, heartburns, and nausea with (1.4%), and anti-helminthic, backache, purgative, carminative, digestive olba, dyspnea, eonslipation & stimulant, gastritis, jaundice, stomach acidity, gastroenteritis, gastric disorder, wound and purgative are reported rare with (0.7%) (Table. 3 & Fig. 6).

Table. 3 Medicinal folk uses of local plants in Tehsil Takht Bhai, district Mardan, KP, Pakistan.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		15	10.9	10.9	10.9
	Abdomen-swelling (Bloating)	5	3.6	3.6	14.5
	Anemia	3	2.2	2.2	16.7
	Anti-helminthic	1	0.7	0.7	17.4
	Antacid	1	0.7	0.7	18.1
	Backache	9	6.5	6.5	24.6
	Burning wound	2	1.4	1.4	26.1
	Carminative	1	0.7	0.7	26.8
	Chicken fox	5	2.5	1.4	28.3
	Purgative	1	0.7	0.7	31.2
	Constipation	9	5.6	5.6	36.2
	Diabetic	12	8.7	8.7	46.4
	Digestive olba	1	0.7	0.7	47.1
	Indigestion	2	0.8	0.8	47.8
	Dry cough	6	4.3	4.3	52.9
	Dysentery	5	3.5	3.8	55.1
	Dyspnea	1	0.7	0.7	56.5
	Appetizers	2	1.4	1.4	58.0
	Eonslipation & Stimulant	1	0.7	0.7	58.7
	Gastritis	1	0.7	0.7	59.4
	Gonorrhea	4	2.9	2.9	62.3
	Hemorrhoids	5	3.6	3.6	65.9
	Urinary tract infection	8	5.6	5.6	71.7
	Jaundice	1	0.7	0.7	72.5
	Laxative	4	2.9	2.9	75.4
	Oligospermia	4	2.9	2.9	78.3
	GERD	1	0.7	0.7	79.0
	Vomiting	3	2.2	2.2	81.2
	CVS disease	2	1.4	1.4	82.6
	Duodenal ulcer	3	2.8	2.8	84.8
	Scabies	4	2.9	2.9	87.7
	Stomach acidity	1	0.7	0.7	88.4
	Stomach discomfort	4	2.9	2.9	91.3
	Gastroenteritis	1	0.7	0.7	92.0

Peptic ulcer	4	2.8	2.8	93.5
Heartburns	2	1.4	1.4	94.9
Used as a purgative	1	0.7	0.7	97.1
Nausea	2	1.4	1.4	98.6
Gastric disorders	1	0.7	0.7	99.3
Wound	1	0.7	0.7	100.0
Total	138	100.0	100.0	

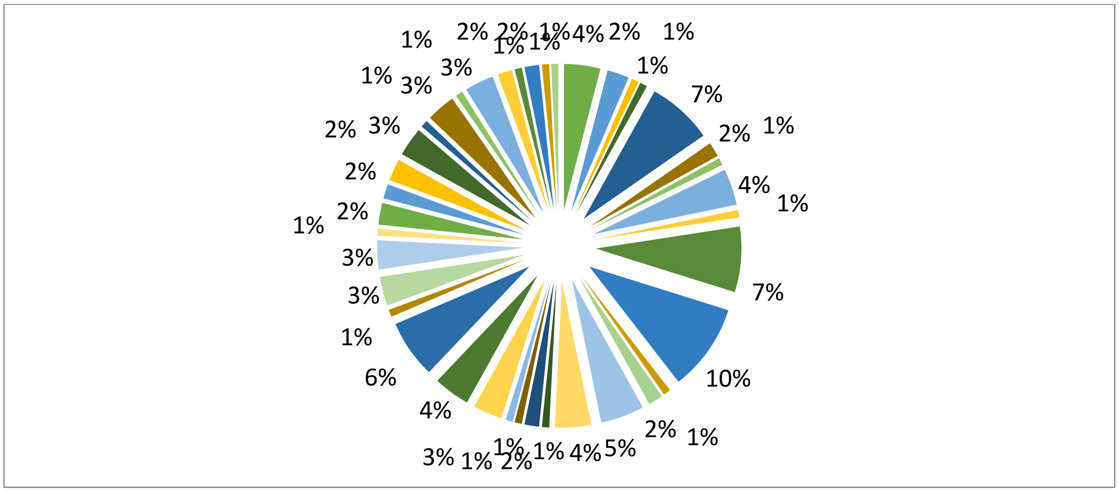

Fig. 6 Shows medicinal folk uses of local medicinal plants.

Parts used of local medicinal plants

According to responses to the question about the parts uses of medicinal plants, the most commonly used part was fruits (24.6%), followed by bark (15.2%), whole plant (5.1%), roots (3.6%), stems (3.6%), flowers (1.4%), and seeds (1.4%). The local inhabitants provide information that the plant parts were used partially for various domestic purposes (Table. 4; Fig. 7).

Table. 4 Parts used of medicinal plant in Tehsil Takht Bhai, district Mardan, KP, Pakistan.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		104	75.4	75.4	75.4
	Fruits	34	24.6	24.6	100.0
	Bark	21	15.2	15.2	100.0
	Stem	5	3.6	3.6	99.3
	Flower	2	1.4	1.4	100.0
	Roots	5	3.6	3.6	100.0
	Seed	2	1.4	1.4	100.0
	Whole plant	7	5.1	5.1	100.0
	Total	138	100.0	100.0	

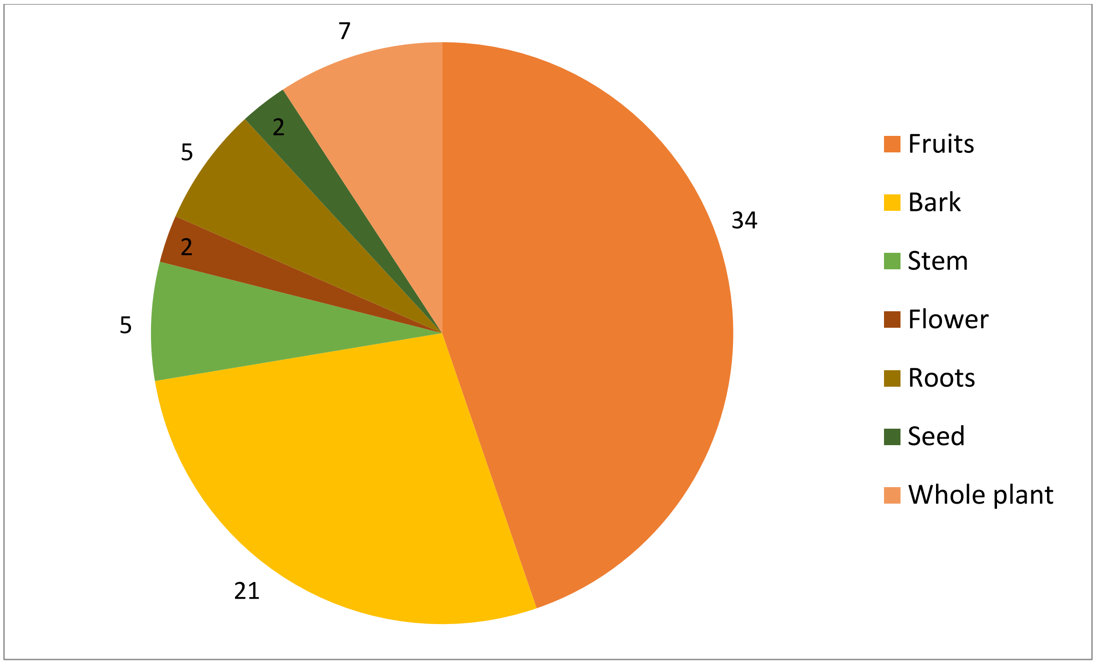

Fig. 7 Shows parts used of local medicinal plants.

Method of uses of local medicinal Plants

It is evident from the results that only 9 recipes are in common use by local inhabitants of the study area. Most of the inhabitants (29.7%) used the powder form of plant parts, followed by (28.3%) used the crushing or grinding form, (15.2%) used directly, (11.6%) used by chewing, (7.2%) used boiling with water, (5.1%) used as a decoction, (1.4%) used as boil with tea, and (0.7%) carminative and mixed with oil (Table.5; Fig. 8).

Table. 5 Use value of different recipes with medicinal plants for curing different diseases in tehsil Takht bhai, district Mardan, KP, Pakistan.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Boil with tea	2	1.4	1.4	1.4
	Boil with water	10	7.2	7.2	8.7
	Carminative	1	0.7	.7	9.4
	Chewing	16	11.6	11.6	21.0
	Crushing	39	28.3	28.3	49.3
	Decoction	7	5.1	5.1	54.3
	Direct use	21	15.2	15.2	69.6
	Mixed with oil	1	0.7	.7	70.3
	Powder	41	29.7	29.7	100.0
	Total	138	100.0	100.0	

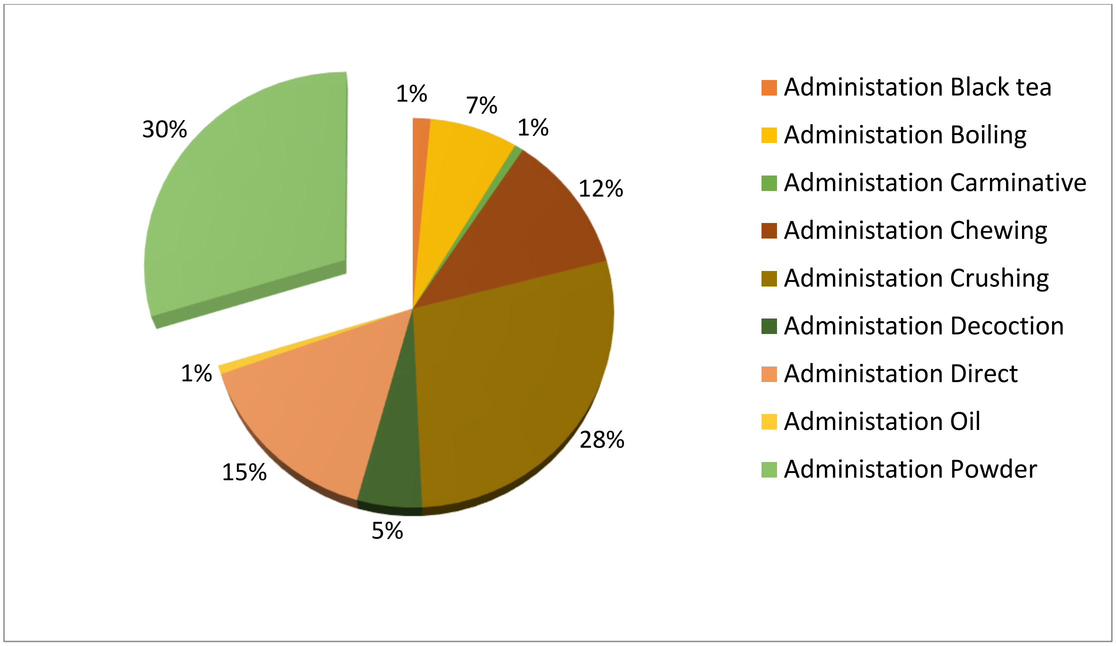

Fig. 8 Shows various plant recipes of the local medicinal plants.

Discussion

Plants are the primary producers and have the ability to synthesize their own food material via Photosynthesis and transfer minerals, gasses and water to other living things. Along with food plants also supply dyes, building material, fiber, landscape, cosmetics and medicines to human being as well as control air pollutions. Plants play important role in our lives because plants help in the reusing of various functional nutrients, and provide us herbal medicines (Ajaib *et al.*, 2013; Ajaib *et al.*, 2014; Maleki & Akhani, 2018). In Pakistan there are about 5000 traditional herb Practitioners (Hakeem), and more than 75% population of the country taking conventional remedies for their ailments on the recommendation of herb practitioners (Ahmad *et al.*, 2012; Barnes *et al.*, 2003). For the livelihoods of poor communities' medicinal plants are very important all over the world (Shinwari *et al.*, 2011).

The study area Tehsil Takht Bhai of district Mardan, Pakistan, is well known for its diverse plant's biodiversity and enrich with traditional knowledge of local communities. The ethnobotanical study used a comprehensive approach, including focus in groups, interviews, and in-depth field surveys with the residents, together this precious knowledge. The researchers observed many different plants and found that some were used extensively. These plants include *Prunus domestica (plum), Diospyros kaki* (Persimmon), *Psidium guajava* (guava), *Punica granatum* (pomegranate), and *Ficus carica* (Fig) etc. These plants' leaves, fruits, and roots were the most frequently used parts. The local people attached with these plant resources for many purposes, ranging from food and medicinal applications to fuel, fodder, and building materials. However, the study identified 56 plant species with medicinal properties that extended beyond common ailments like colds and flu, including treatments for fever, cough, cold, diarrhea, and various skin conditions. This abundance of knowledge in drug development and contemporary pharmaceutical research is crucial because it can open the door to developing novel, affordable, and effective medications. Therefore, the interaction of the region's traditional medicinal knowledge, biodiversity, and uses of plants highlights the possibility of comprehensive advances in science and medicine (Amjad *et al.*, 2020; Iqbal *et al.*, 2021; Ozioma & Chinwe, 2019).

Mostly, local people with age group are 60 (9.4%), having more knowledge about the ethnobotanical uses of medicinal plants, followed by age group 70 (8.7%). The local interviewers were mostly male 133 (96.4%) out of 138 respondents. According to the interview of local respondents the people having more ethnobotanical knowledge were usually illiterate (23.9%) and gain more knowledge from practically life experiences (Cheng *et al.*, 2022; Khajuria *et al.*, 2021). Medicinal folk uses, the local respondents reported various parts of the medicinal plants are used for different diseases i.e., 8.7% of respondents used it for diabetic, 6.5 % used it for backache, 5.6 % used it for constipation and urinary tract infection, 4.3% used it for dry cough, 3.6% used it for abdominal swelling and hemorrhoids, 3.5% used it for dysentery, 2.9% used it for laxative, oligospermia, scabies, stomach discomfort, gonorrhea, laxative, 2.8% used if for duodenal ulcer and peptic ulcer, 2.5% used it for chicken fox, 2.2 % used it for anemia and vomiting, 1.4% used it for burning wound, appetizers, CVS disease, heartburns, and nausea, and 0.7% used it for anti-helminthic, backache, purgative, carminative, digestive olba, dyspnea, eonslipation & stimulant, gastritis, jaundice, stomach acidity, gastroenteritis, gastric disorder, wound and purgative (Ali *et al.,* 2017; Ali *et al.,* 2017; Arshad *et al.*, 2020; Hrichi *et al.*, 2020; Karakose *et al.*, 2019; Rahman *et al.*, 2019).

Parts used, according to local interviewers the most commonly used plant parts were fruits, bark, whole plant, roots, stems, flowers and seeds, 24.6% of the respondents used its fruits, 15.2% respondents used plant bark, 5.1% respondents used whole plant, 3.6% respondents used plant stem and roots, 1.4% respondents used plant flowers, and 1.4% respondents used plants seeds accordingly (Ali *et al.,* 2017; Khare *et al.,* 2021; Usman *et al.,* 2021). Method of uses, the local respondents reported various method of uses. 29.7% of the respondents used it in powder form, 28.3% respondents used it in simple crushing form, 15.2% used it directly, 11.6% respondents used it in chewing form, and 7.2% respondents used it boiling with water, 5.1% used it as a decoction, 1.4% used it boiling with tea, and 0.7% used it mixed with oil (Ali *et al.,* 2017; Jan *et al.,* 2021).

Conclusions

Finally, in the light of the findings of the present study, the following conclusion were drawn. We conclude that medicinal plants commonly grown in the local Tehsil Takht Bhai of the district Mardan increase the local biodiversity of the area. We also conclude that the plants are highly medicinal and vast uses as an ethno-medicinal. 8.7% of respondents used it for diabetic, 6.5 % used it for backache, 5.6 % used it for constipation and urinary tract infection, 4.3% used it for dry cough, 3.6% used it for abdominal swelling, 3.5% used it for dysentery, 2.9% used it for laxative, oligospermia, scabies, stomach and discomfort, 2.8% used if for duodenal ulcer and peptic ulcer, etc. According to the opinion of local inhabitants the commonly plants parts were used as fruits (24.6%), bark (15.2%), whole plant (5.1%0, roots (3.6%), stem (3.6%), flowers (1.4%) and seeds (1.4%). The local people also opinion that the plants are used by various methods i.e., powder (29.7%), crushing (28.3%), direct use (15.2%), chewing (11.6%) and boiling (7.2%). The people of old age interviewed showed better knowledge of the ethno-medicinal of the species. We believe that due to modernization of our society, people are not pay attention to the conservation and preservation of the important ethno-botanical knowledge. We recommended for the young researchers that further studies on the local flora should be carried out in the area and the species need special attention of conservation for the next generation. Also, we recommend that the area having more potential of ethno-botanical knowledge, so explore the whole district Mardan and save the precious knowledge. We are thankful for the local interviewers for taking part and sharing their valuable knowledge.

Declarations

Funding: This study received no external funding.

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Author's Contribution: Tariq Jamal and Fazli Malik Sarim conceived the idea, Imtiaz Ahmad, Yasmeen Begam designed methodology, Sheema and Jaweria helps in data collection, Aziz Ur Rahman design references, Shah Faisal and Sapna Umar helps in data analysis, Farman Ullah helps in scientific writing and make final drafts, and final approval.

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RESEARCH ARTICLE

Effect of the Integrated Weed Control Practices on Sugar Beet Yield, Quality and Associated Weeds

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Abstract
Two-years field trial (2017/18 and 2018/19) was conducted at the Experimental Farm, National Research Centre El-Behaira Governorate, Egypt to compare different herbicidal combinations with different doses on sugar beet yield traits and associated weeds. Sixteen weed control treatment combinations were applied to test their efficiency on sugar beet yield and quality. To form these combinations two broadleaves herbicides (Tigro and Betasana-Trio) were combined with a narrow weed herbicide (Select super) or with the hand weeding treatment. The results showed that Betasana-Trio combination at the lower dose of application 0.675 l fed^{-1}(fed^{-1} = feddan = 4200 m^2) combined with Select Super at 0.375 l fed^{-1} with or without hand weeding as well as Betasana-Trio at 0.9 l fed^{-1} combined with hand weeding or Select Super at 0.5 l fed^{-1} caused high eradication percentages of the total fresh and dry weight of weeds as well as total number of weeds m^{-2} (>90%). The highest sugar beet yield resulted from the combination of Betasana-Trio 0.675 l fed^{-1} + Select Super 0.375 l fed^{-1}, which gave the greatest sugar yield fed^{-1}. Although the combination Betasana-Trio at 0.9 l fed^{-1} + Select Super at 0.5 l fed^{-1} gave the greatest gross sugar %, it could not achieve the highest sugar yield fed^{-1}.

Key words: Herbicides; sugar beet productivity; sugar quality; weed competition; weed management

Introduction

Sugar beet (*Beta vulgaris* L.) ranks as the second most important sugar crop worldwide after sugar cane. (*Saccharum ofcinarum* L.) (Brar *et al*., 2015). Sugar beet is a temperate crop and its root contains a high amount of sucrose (Paul *et al*., 2019). The total global cultivated acreage of about 4.4 mega tons (Mt) produces approximately 253 Mt of sugar beet roots that provides ~ 30% of the gross world's requirements of white sugar (FAO 2022). However, sugar beet production worldwide is frequently faced ecological challenges (Abd El-Mageed *et al*., 2022; Makhlouf *et al*., 2022) and biotic stresses such as weeds. It is well known that weeds interfere with crop plants causing serious impacts either in the competition for light, water, nutrients and space or in the allelopathy. Weeds suppression by shading only begins after the canopy of sugar beet leaves grown over the rows and early coverage of field. Faster growth of weeds is disadvantageous for light and hence photosynthesis needed for sugar beet plants.

Through this light deprivation less energy is available to crop plant for metabolic production and hence growth, yield and quality of sugar beet will be reduced. In addition, weeds with branched, vigorous root systems inhibit the development of sugar beet plants through severe nutrition deprivation. Competition between sugar beet and annual weeds could be responsible for sugar yield reductions of 25-100% (Poorazar and Ghadiri, 2001). Weed control in crops is mainly based on the use of herbicides because they are efficient and easily applied (Lodovichi *et al*., 2013). The use of herbicides may reduce yield losses, as herbicides can reduce the weed infestation (Mehmeti, 2004). Majidi *et al*. (2011) showed that using a combination of broad-leaved herbicides caused weeds to be controlled and root yield to be increased. Weed control is decisive and one of the most difficult agricultural arrangements in sugar beet growing because of low crop interference with weeds (Jursík *et al*., 2008). The evaluated herbicidal control is a very effective strategy for weed control in sugar beet. Majidi *et al*. (2017) reported that several herbicides are registered for selective weed control in sugar beet; however, no single chemical herbicide can control all weeds in beet fields. Frequently, few herbicides may have to be combined sequentially or as tank mixed to achieve adequate broad-spectrum weed control. Hand hoeing still the conventional weed control practice in sugar beet in Egypt. In recent years, the hand labor is becoming scarce and their wages have been increased. However, the manual weeding could not be perfectly provided. This in turn presents to view the needs for another reasonable alternative. Herbicide treatment alone surpassed some hand hoeing treatments. In this respect, Abo El-Hassan (2010) found that root length, root diameter, root weight, top fresh weight, top yield, root yield, sugar yield of sugar beet were significantly affected by weed control treatments. Also, Tagour *et al*. (2012) found that two hoeing with mulching gave the highest values of tops, roots, biological and sugar yields.

The current research hypothesized that using different herbicide combinations with different doses will have better efficiencies for controlling weeds than conventional methods, hence improving sugar beet yield and quality. Therefore, this study aimed to assess the effect of diversified broad and narrow leaf herbicides types and combination between them compared to the common practices (hoeing) on weed growth, sugar beet yield and quality.

Materials and methods

During the winter seasons of 2017/18 and 2018/19, two field experiments were conducted at the Experimental Farm, National Research Centre El-Behaira Governorate, Egypt (30.30° N, 30.18° E and 21 m above sea level).The experimental soil was sandy with a pH and EC of 8.3 and 0.38 dS m^{-1}, respectively. The experiments were conducted to compare different herbicide combinations with different doses on sugar beet yield characters and associated weeds. Two broad leave weeds herbicides (Tigro and Betasana-Trio) were combined with a narrow weed herbicide (Select Super) or with the hand weeding treatment. The treatments were as follow:

1. Tigro 1.0 l fed^{-1}
2. Tigro 0.750 l fed^{-1}.
3. Tigro 1.0 l fed^{-1} + Select Super 0.5 l fed^{-1}.
4. Tigro 1.0 l fed^{-1} + Select Super 0.375 l fed^{-1}.
5. Tigro 0.750 l fed^{-1} + Select Super 0.375 l fed^{-1}.
6. Tigro 1.0 l fed^{-1} + HW.
7. Tigro 0.750 l fed^{-1} + Select Super 0.375 l fed^{-1} + HW.
8. Betasana-Trio 0.9 l fed^{-1}.
9. Betasana-Trio 0.675 l fed^{-1}.
10. Betasana-Trio 0.9 l fed^{-1} + Select Super 0.5 l fed^{-1}.
11. Betasana-Trio 0.9 l fed^{-1} + Select Super 0.375 l fed^{-1}.

12. Betasana-Trio 0.675 l fed^{-1} + Select Super 0.375 l fed^{-1}.
13. Betasana-Trio 0.9 l fed^{-1} + HW.
14. Betasana-Trio 0.675 l fed^{-1} + Select Super 0.375 l fed^{-1} + HW.
15. Hand weeding twice.
16. Unweeded control.

The herbicides were sprayed after sowing according to the stages indicated for each herbicide in Table 1. Sowing date was on 21st November 2017 and 2018 seasons. The Experimental design was a randomized complete block design (CRBD) in three replications.

Table 1. Common, trade and chemical names of used herbicides as well as, mode of action, rate and time of application.

Common name	Trade name	Chemical name	Mode of action	Rate of applicatio n fed^{-1}	Time of application
Ethofumesat e	Betasana-Trio	Ethofumesate – 115g/l (11.5% w/w) Phenmedipham – 75g/l (7.65% w/w) Desmedipham- – 15g/l (1.55% w/w)	Classical Photosynthes is inhibitors	900 cm+900 cm	At the age of two real leaf on sugar beet and repeat treatment after 8 days
Phenmediph am	Tigro 27.4/EC	- 91g/l Desmedipham- 71g/l Ethofumesate – 112g/l	Classical Photosynthes is inhibitors	1.0 L	At the age of two real leaf on sugar beet
Clethodium	Select Super	(±)-2-[(E)-1-[(E)-3-chloroallyloxyimino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxycyclohex-2-enone	Lipid Biosynthesis inhibitors	500 cm	At the age of 2-4 real leaf of weeds

Studied Characters

Weed flora

A sample of weeds in 1 m^2 was taken from each experimental unit to determine the number and fresh weights of broad leave, narrow leave and total weeds. The eradication % of weeds was calculated as follows:

Eradication % (fresh weight m^{-2}) = (Weeds fresh weight of treatment – weeds fresh weight of unweeded control)/ weeds fresh weight of unweeded control x 100

Eradication % (fresh weight m^{-2}) = (Weeds dry weight of treatment – weeds dry weight of unweeded control)/ weeds dry weight of unweeded control x 100

Eradication % (No. of weeds m^{-2}) = (Weeds No. of treatment - weeds No. of unweeded control)/ weeds No. of unweeded control x 100

- Plant samples were taken from three replicates and 10 plants were taken from each experimental unit to estimate root characters involving root length (cm), root diameter (cm), root weight (g) and top weight per plant (g).

- Total chlorophyll content of sugar beet leaves were determined by SPAD value was determined at 90 days according to chlorophyll meter (SPAD-502, Minolta Camera Co., Osaka, Japan, Minolta Co., 1989).
- Yield per fed: Number of plants in the experimental unit area were counted and top and roots weights of 3*3.5 m were determined, then total yield was calculated.

Twenty roots from each plot were randomly taken to determine root quality and technological characteristics at Quality Control Laboratory, El-Nubaria Sugar Factory and El-Behera, Egypt. Sucrose % was determined using Saccharometer according to the method described in AOAC (2012). According to Cooke and Scott (1993) impurities (potassium (K), sodium (Na), and alpha amino nitrogen (α-amino N) were estimated. Moreover, juice purity using Eq. 1 was estimated (Cooke and Scott 1993). After that, sugar yield ha^{-1} was calculated using Eq. 2 as reported by Deviller (1988).

Juice purity % = (Extractable sugar % ⁄ sucrose %) × 100 (1)

Sugar yield (fed^{-1}) = Root yield (fed^{-1}) × extractable sugar % (2)

Statistical analysis

The analysis of variance was carried out using MSTATC Computer Software (MSTAT-C, 1988) after testing the homogeneity of the error by Bartlett's test. Combined analysis for both seasons was done. Means of the different treatments were compared using the least significant difference (LSD) at 5% level of probability.

Results and discussion

Effect of weed control treatments on weed traits

The dominant weed specious in the experiment included common sweet clover (*Melilotus indica* L.), wild beet (*Beta vulgaris* L.), Greater Ammi (*Ammi majus* L.) and London rocket (*Sisymbrium irio* L.) as broadleaved weeds as well as wild oat (*Avena fatua* L.) and ryegrass (*Lolium temulentum* L.) as narrow-leaved weeds. Several investigators reported that approximately 70% of weed species in sugar beet fields are mainly broadleaf annual such as redroot pigweed (*Amaranthus retroflexus*) (Weaver and Williams, 1980; Schwizer and May, 1993 and Heidari *et al*., 2007).

Data in Table 2 show weed flora of the two broad-leaved herbicides regardless herbicide combination. The two herbicides differed significantly in their effect on fresh weight of narrow leaf weeds and dry weight of broad, narrow and total weights as well as number of broad, narrow weeds m^{-2} after 90 days from sowing. The data showed that both herbicides were similar in the eradication of fresh, dry and total number of weeds / after 90 days from sowing Figure 1.

Table 2. Effect of broad leaved herbicides on weed characteristics

Herbicide	Weeds fresh weight ($g\ m^{-2}$)			Eradi-cation* %	Weeds dry weight ($g\ m^{-2}$)			Eradi-cation %	Weeds number m^{-2}			Eradi-cation %	~~SPAD~~
	Broad leaves	Narrow leaves	Total		Broad leaves	Narrow leaves	Total		Broad leaves	Narrow leaves	Total		
Tigro	83.9	131.0	215.0	77.0	14.4	32.5	43.8	97.0	36.5	32.4	68.9	79.8	~~46.8~~
Betasana-Trio	80.0	135.0	215.0	77.0	158.1	29.4	190.5	86.4	34.8	32.1	66.9	80.4	~~45.3~~
LSD 0.05	Ns	1.9	ns	-	2.2	0.5	1.7	-	7.4	5.1	ns	-	~~1.2~~

*relative to the unweeded control

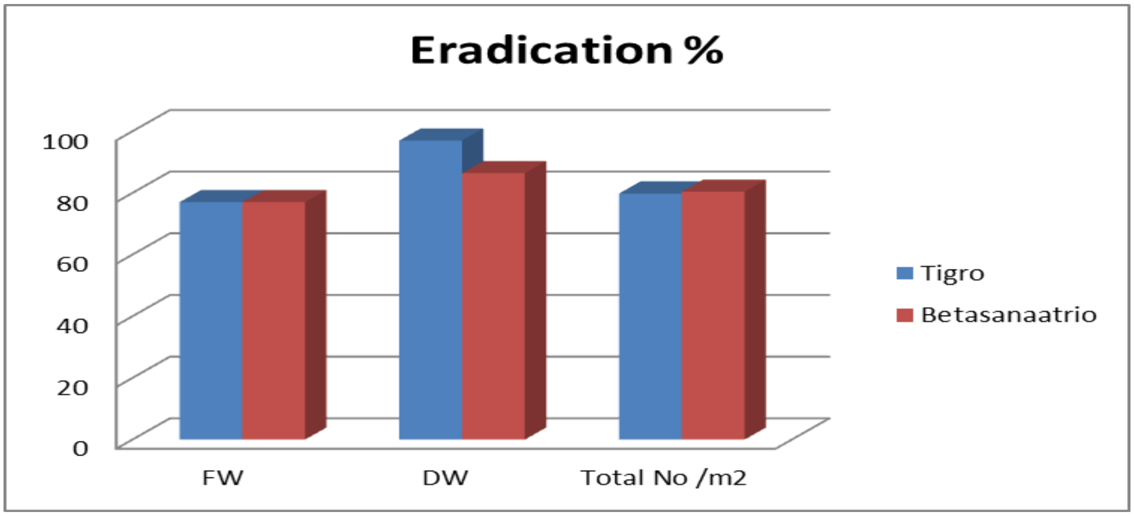

Figure 1. Effect of broad leaved herbicides on weed eradication

Data in Table 3 show that weed control treatments differed significantly in their effect on fresh and dry weight of broad, narrow and total weights as well as number of broad, narrow, and total number of weeds m^{-2} after 90 days from sowing. The data showed that Tigro at 0.750 l fed^{-1}, Betasana-Trio at 0.9 or at 0.675 l fed^{-1} sprayed twice could effectively and completely eliminate the broad-leaved weeds associated with sugar beet plants so the number or fresh and dry weights are nil. Also, the application of Tigro at the lower dose combined with the herbicide Select Super as well as Betasana-Trio combination at 0.900 l fed^{-1} with Select Super at 0.375 l fed^{-1} or one hand weeding or Betasana-Trio combination at 0.675 l fed^{-1} with Select Super at 0.375 l fed^{-1} could effectively and completely eliminate fresh and dry weeds weight of broad, narrow ant total fresh and dry weight of the associated weeds as well as weed numbers m^{-2}. Data in the same table show that Tigro combination at 1.0 l fed^{-1} with Select Super at 0.375 l fed^{-1} or with hand weeding resulted in the highest eradication percent of the total fresh, dry weights and total number of weeds of weeds m-2 > 90%. Similarly, Betasana-Trio combination at the lower dose of application combined with Select Super at 0.375 l fed^{-1} with or without hand weeding as well as Betasana-Trio at 0.9 l fed^{-1} combined with hand weeding or Select Super at 0.5 l fed^{-1} attained high eradication percent of the total fresh and dry weight of weeds as well as the total number of weeds m^{-2} (> 90%). Several investigators pointed out those individual sugar beet herbicides seldom have a wide enough weed control spectrum or sufficient residual activity to control all weeds (Abdollahi and Ghardiri, 2004). The optimization of herbicide application in the sugar beet protection system can be achieved by using mixtures of appropriate components and their selected doses. In this regard, application of acetolactate synthase (ALS) inhibiting herbicides achieved excellent efficacy on common sugar beet weeds (Gotze *et al*. 2018). Furthermore, Jursík *et al*. (2020) recorded that DELP herbicide completely controlled *Amaranthus retrofexus* L.*, Echinochloa crus-galli* L., and *Chenopodium album* L. in sugar beet. Several studies demonstrated good weed control with reduced herbicide doses (Deveikyte and Seibutis, 2006; Kucharski, 2009 and Najafi *et al*., 2013). Moreover, Goleblowska and Domaradzki (2010) reported that a 50% and 67% dose of Betanal Progress + Goltix + Safari and Betanal Progress + Venzar + Safari consistently produced 94-97% weed annihilation. The half dose of herbicides reduced weed biomass significantly (Najafi *et al*., 2013).

Table 3. Effect of weed control treatments on weed characteristics

Weed control treatment	Fresh wt. broad leaves weeds m^{-2}	Fresh wt. Narrow leaves weeds m^{-2}	Total fresh wt. m^{-2}	Eradi-cation %	Dry wt. of broad weeds m^{-2}	Dry wt. of narrow weeds m^{-2}	Total dry wt. m^{-2}	Eradi-cation %	No. of Broad weeds m^{-2}	No. of narrow weeds m^{-2}	Total no. of weeds m^{-2}	Eradic-ation %
Tigro 1.0 l fed^{-1}	28.3	236.7	265.0	72.1	4.95	52.7	57.6	68.1	12.3	58.5	70.8	79.3
Tigro 0.750 l fed^{-1}	0.1	183.1	183.2	80.7	0.10	40.8	40.9	77.4	0.1	43.4	43.5	87.2
Tigro 1.0 l fed^{-1}+ Select Super 0.5 l fed^{-1}	0.1	20.5	20.6	97.8	0.10	4.6	4.7	97.4	0.1	4.9	5.0	98.5
Tigro 1.0 l fed^{-1} + Select Super 0.375 l fed^{-1}	0.1	238.1	238.2	74.9	0.10	53.0	53.1	70.7	0.1	56.4	56.5	83.4
Tigro 0.75 l fed^{-1} +Select Super 0.375 l fed^{-1}	42.5	86.1	128.6	86.4	7.33	19.2	26.5	85.3	18.5	20.5	39.0	88.8
Tigro 1.0 l fed^{-1}+ HW	39.1	34.7	73.8	92.2	6.75	7.8	14.5	92	17.0	15.1	32.1	90.8
Tigro 0.75 l fed^{-1}+ Select Super 0.375 l fed^{-1} + HW	13.9	0.1	14.0	98.5	2.45	0.1	2.5	98.6	6.1	0.1	6.2	97.9
Betasana-Trio 0.9 l fed^{-1}	0.1	229.0	229.1	75.9	0.10	51.0	51.1	71.7	0.1	54.3	54.4	84.0
Betasana-Trio 0.675 l fed^{-1}	0.1	77.7	77.8	91.8	0.10	17.4	17.5	90.3	0.1	18.5	18.6	94.3
Betasana-Trio 0.9 l fed^{-1} + Select Super 0.5 l fed^{-1}	0.1	0.1	0.2	99.9	0.10	0.1	0.2	99.9	0.1	0.1	0.2	99.9
Betasana-Trio 0.9 l fed^{-1} (twice) + Select Super 0.375 l fed^{-1}	0.1	300.1	300.2	68.4	0.10	66.8	66.9	63	0.1	71.1	71.2	79.1
Betasana-Trio 0.75 l fed^{-1} (twice) + Select Super 0.375 l fed^{-1}	87.9	221.7	309.6	67.4	15.09	49.4	64.4	64.4	38.2	52.6	90.7	73.2
Betasana-Trio 0.9 l fed^{-1} (twice) + HW	0.1	0.1	0.2	99.9	0.10	0.1	0.2	99.9	0.1	0.1	0.2	99.9
Betasana-Trio 0.675 l fed^{-1} + Select Super 0.375 l fed^{-1}+ HW	0.1	0.1	0.2	99.9	0.10	0.1	0.2	99.9	0.1	0.1	0.2	99.9
HW Twice	40.7	27.9	68.6	92.8	7.02	6.26	13.28	92.7	17.74	6.66	24.4	92.6
Unweeded control	591.1	359.9	951	-	100.94	80.06	181	-	256.62	85.26	-	342.0
LSD at 0.05	17.33	18.69	17.65	-	11.36	3.83	10.79	-	7.53	5.07	7.02	-

Yield

Data in Table 4 show the single effect of the broad-leaved herbicides on sugar beet crop characteristics regardless herbicide combination. The two herbicides differed significantly in their effect on chlorophyll content expressed as SPAD value. The data showed that both herbicides were similar in the studied characters except root weight and length per plant.

Table 4. Effect of broad leaved herbicides on sugar beet yield characteristics.

Herbicide	SPAD value	Root Wt. (g)	Shoot yield (g)	Root length (cm)	Root diameter (cm)	Stand thousand plants fed^{-1}	Biological yield fed^{-1} (t)	Root yield fed^{-1} (t)	FW. yield fed^{-1} (t)
Tigro	46.8	354.0	104.0	28.9	8.0	37.3	32.7	25.2	7.5
Betasana-Trio	45.3	457.0	116.0	30.1	8.3	36.2	37.0	28.8	8.2
LSD at 0.05	1.2	49.1	ns	1.25	ns	ns	Ns	ns	ns

Effect of different herbicide combinations on sugar beet traits

Chlorophyll content

The chlorophyll content data expressed as SPAD reading indicate that there is no clear tendency of the tested herbicides in their effect on chlorophyll content of sugar beet leaves (Table 5). However, Tigro combination at 1.0 l fed^{-1} with Select Super at 0.375 l fed^{-1} or with hand weeding and Betasana-Trio at the higher dose of application (1.0 and 0.9 l fed^{-1}) recorded the greatest chlorophyll content in sugar beet leaves as compared with the other weed control treatments, whereas the lowest chlorophyll content was recorded by the unweeded control. There were no significant differences among the other herbicidal treatments and hand weeding twice in SPAD values. Although the mode of action of the most of these herbicide combinations is a classical photosynthesis inhibitor but similarly they possessed higher selectivity and did not affect the sugar beet leaf chlorophyll content.

Yield traits

Data in Table (5) show significant differences in root yield plant^{-1}. The greatest significant root yield plant^{-1} was recorded when the herbicide Betasana-Trio was applied at the lower dose tested (0.675 l fed^{-1}) combined with hand weeding. The differences among other weed control treatments on root and shoot yields plant^{-1} were insignificant. The greatest shoot yield plant-1 was reported when Betasana-Trio was applied at the lower dose tested (0.675 l fed^{-1}) combined with hand weeding. Data in the same table show significant differences among weed control treatments in their effect on sugar beet root length and diameter. The greatest significant root length was recorded when the herbicide Tigro was applied at the lower dose tested (0.750 l fed^{-1}). The difference between other weed control combinations and hand weeding twice in root length was insignificant in this criterion. The greatest root diameter was recorded by Betasana-Trio when applied alone at 0.675 l fed^{-1} or combined with Select Super at 0.375 l fed^{-1}. The greatest top weight fed^{-1} was reported when Tigro was applied at 1.0 l fed^{-1} combined with Select Super at 0.375 l fed^{-1} or when Betasana-Trio was applied alone at 0.675 l fed^{-1} or combined with Select Super at 0.375 l fed^{-1} without significant difference with the hand hoeing twice treatment. The difference among other treatments were insignificant in top weight fed^{-1}. From the same Table (13), there were significant differences among weed control treatments in root and biological yields fed^{-1}. The data of root and biological yields fed^{-1} took similar tendency and the greatest significant root yield fed^{-1} was recorded when the herbicides Tigro was applied at 1.0 l fed^{-1} combined with Select Super at 0.375 l fed^{-1} or when Betasana-Trio was applied alone at 0.675 l fed^{-1} or combined with Select Super at 0.375 l fed^{-1} followed by hand weeding twice without significant differences. Soroka and Gadzhieva (2006) reported that when sugar beet and weeds grow together 30 days after emergence of sugar beet, the root yield is decreased by up to 45%). Also, Majidi *et al*. (2011) reported that the use of herbicides may reduce yield losses, as herbicides can reduce the weed infestation. Mehmeti (2004) showed that using a combination of broad-leaved herbicides caused weeds to be controlled and root yield to be increased.

Table 5. Effect of different herbicide combinations on sugar beet yield traits.

Treatment	SAPD value	Root length (cm)	Root diameter (cm)	Root weight (g)	Shoot weight (g)	Root yield fed^{-1} (ton)	Shoot Yield fed^{-1} (ton)	Biological yield fed^{-1} (ton)
Tigro 1.0 l fed^{-1}	46.5	30.0	7.0	301.1	84.1	24.1	6.3	30.4
Tigro 0.750 l fed^{-1}	43.4	36.7	8.6	597.6	72.1	33.1	3.9	37.0
Tigro 1.0 l fed^{-1} + Select Super 0.5 l fed^{-1}	49.1	34.5	9.4	474.1	115.4	36.2	8.7	44.9
Tigro 1.0 l fed^{-1} + Select Super 0.375 L fed^{-1}	54.8	33.3	8.9	411.5	193.1	31.6	14.1	45.7
Tigro 0.750 l fed^{-1} + Select Super 0.375 l fed^{-1}	46.4	28.2	7.2	162.9	63.1	13.3	5.2	18.5
Tigro 1.0 l fed^{-1} + HW	51.3	24.3	7.8	184.2	43.8	13.9	3.2	17.1
Tigro 0.750 l fed^{-1} + Select Super 0.375 l fed^{-1} + HW	48.4	28.5	7.3	293.1	101.8	23.1	8.0	31.1
Betasana-Trio 0.9 l fed^{-1} (twice)	52.8	23.7	6.6	272.8	81.6	20.6	6.7	27.3
Betasana-Trio 0.675 l fed^{-1} (twice)	43.5	33.3	9.3	535.2	100.1	34.7	7.1	41.8
Betasana-Trio 0.9 l fed^{-1} (twice) + Select Super 0.5 l fed^{-1}	47.8	31.0	8.3	388.5	129.7	32.5	11.6	44.1
Betasana-Trio 0.9 l fed^{-1} (twice) + Select Super 0.375 l fed^{-1}	45.5	29.7	9.4	530.8	116.8	27.0	1.4	28.4
Betasana-Trio 0.750 l fed^{-1} (twice) + Select Super 0.375 l fed^{-1}	45.4	26.7	7.7	270.6	117.2	18.3	8.0	26.3
Betasana-Trio 0.675 l fed^{-1} + Select Super 0.375 l fed^{-1} + HW	46.5	33.0	9.8	816.0	245.3	39.5	12.6	52.1

Betasana-Trio 0.9 l fed^{-1} (twice) + HW	45.5	28.7	7.9	417.8	106.1	30.1	7.6	37.7
Control	39.4	24.7	7.4	305.8	117.3	19.5	7.7	27.2
HW twice	45.2	30.7	8.7	458.1	145.9	31.52	10.28	41.8
LSD at 0.05	4.85	11.75	3.26	432.1	NS	4.12	10.7	15.87

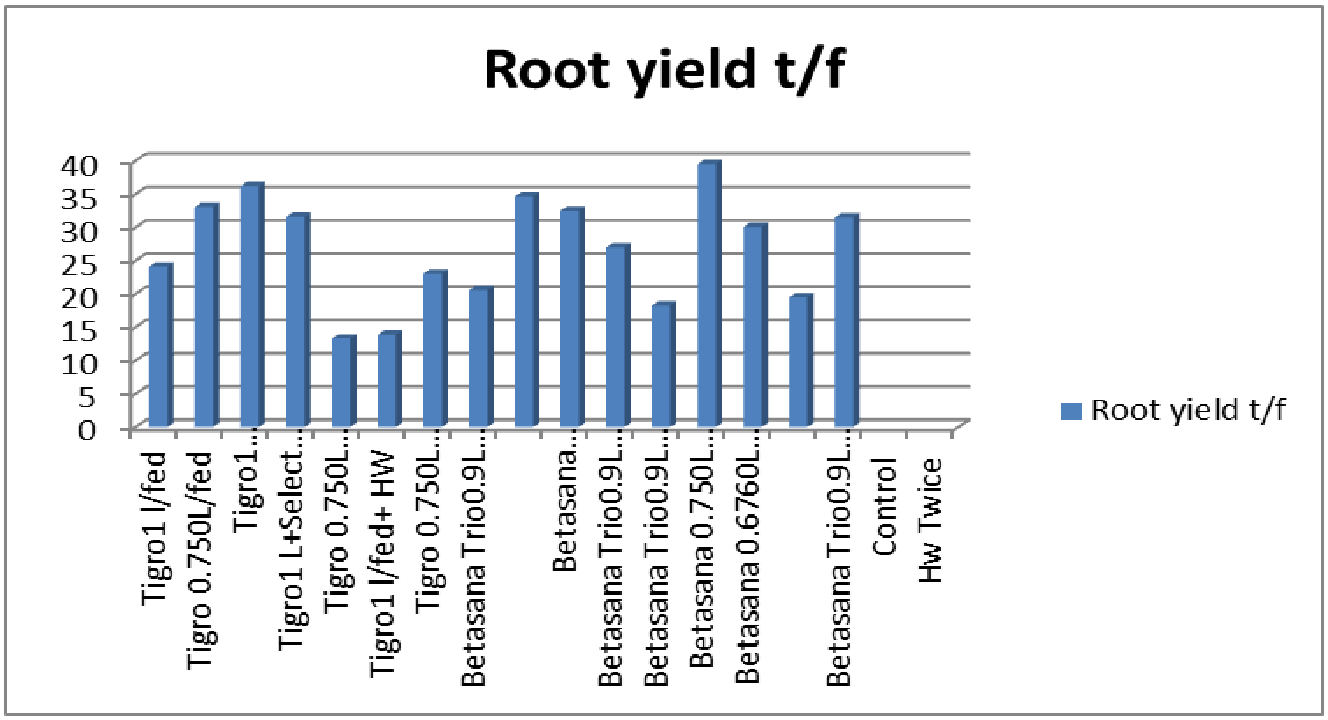

Figure 2. Effect of different herbicide combinations on sugar beet root yield fed^{-1} (t)

Effect of weed control treatments on chemical composition of roots and sugar yield

Data presented in Table (6) show that weed control treatments exhibited clear differences in sugar beet quality parameters, which affected sugar extraction. The highest sugar beet yield resulted from the combination of Betasana-Trio 0.675 l fed^{-1} + Select Super 0.375 l fed^{-1} which gave the highest sugar yield fed-1. Although the combination Betasana-Trio 0. 900 +Select Super 0.5 l fed^{-1} contained the greatest gross sugar % but it could not achieve the highest sugar yield fed-1. Sugar beet plants treated with (Tigro 1.0 l fed^{-1}) possessed the highest purity parameters (increased Qz but it did not contain the lowest soluble non-sugars (potassium, sodium and α-amino nitrogen content of beet). In this respect, Dale *et al*. (2005) found that white sucrose produced per unit area did not differ among post herbicide treatments and sugar and non-sugar contents were not affected by the herbicide treatments. Sugar yield data followed the root yield data because the herbicide did not have any influence on the amount of sugar beet root quality parameters (Dale *et al*., 2006).

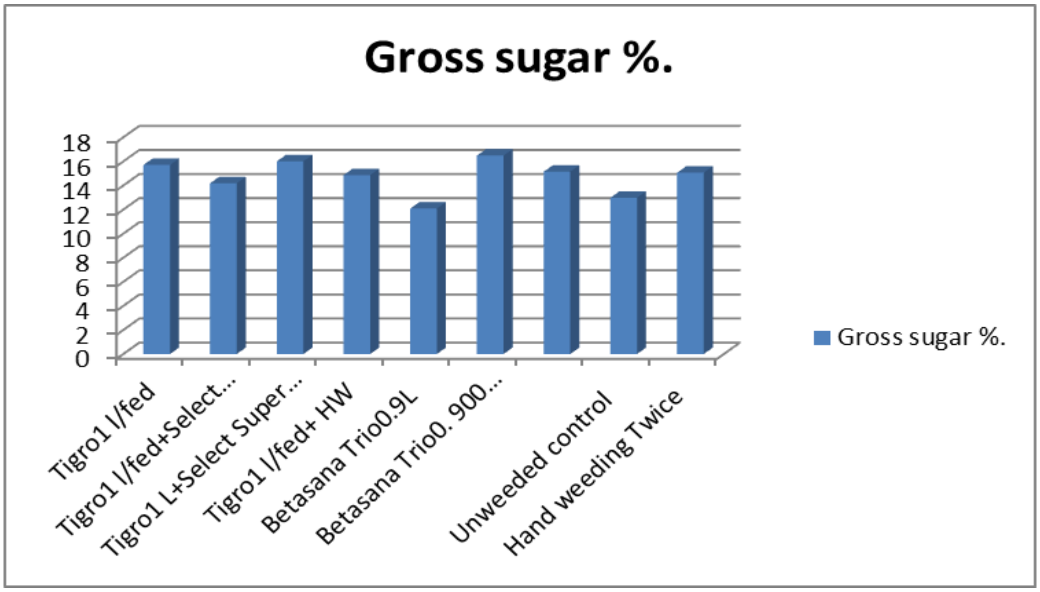

Figure 3. Effect of different weed control treatments on gross sugar %

Table 6. Effect of different weed control treatments on sugar beet quality.

Treatment	Gross sugar %	Juice purity % (Qz)	K	Na	α-amino	Sugar yield fed^{-1} (t)
Tigro 1.0 l fed^{-1}	15.70	80.02	4.16	3.03	4.05	3.78
Tigro 1.0 l fed^{-1} + Select Super 0.5 l fed^{-1}	14.18	78.91	3.72	2.55	5.85	5.13
Tigro 1.0 l fed^{-1} + Select Super 0.375 l fed^{-1}	16.00	79.93	3.78	3.11	5.94	5.06
Tigro1.0 l fed^{-1+} HW	14.86	78.63	3.91	3.06	5.26	2.06
Betasana-Trio 0.9 l fed^{-1}	12.08	74.28	3.65	3.26	4.76	2.48
Betasana-Trio 0.9 l fed^{-1} + Select Super 0.5 l fed^{-1}	16.48	74.99	4.37	3.07	5.62	5.35
Betasana-Trio 0.675 l fed^{-1} + Select Super 0.375 l fed^{-1}	15.14	79.09	3.80	3.40	4.32	5.98
Unweeded control	12.98	69.77	3.85	5.46	4.70	2.53
Hand weeding Twice	15.06	78.53	4.64	3.00	3.40	4.75

Conclusion

It could be concluded that the herbicide combinations of Tigro at the lower dose combined with the herbicide Select Super as well as Betasana-Trio combination at 0.900 l fed^{-1} with Select super at 0.375 l fed^{-1} or one hand weeding or Betasana-Trio combination at 0.675 l fed^{-1} with Select super at 0.375 l fed^{-1} could effectively and completely eliminate fresh and dry weeds weight of broad, narrow ant total fresh and dry weight of the associated weeds as well as weed numbers m^{-2}.

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RESEARCH ARTICLE

Exploring the Effectiveness of Human Waste Compost in Improving Agricultural Soil: A Comparative Study with Poultry Manure, Cow Dung, and Vermicompost

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Abstract
The heightened application of chemical fertilizers to enhance agricultural output jeopardizes agricultural and environmental sustainability. The present study assessed the influence of various organic amendments on soil properties. The experimental design encompassed a Randomized Complete Block Design, with treatments that included a control group along with vermicompost, human waste compost, poultry manure, and cow dung. The primary focus of the experiment was to evaluate multiple soil attributes, such as soil texture, pH, electrical conductivity (EC), organic matter (OM), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), available sulfur (S), and exchangeable sodium (Na), to determine the impact of different manure applications. The findings of the study confirmed significant alterations in soil physicochemical parameters due to the application of these treatments. Notably, poultry manure and vermicompost exhibited the most substantial positive effects on total nitrogen, resulting in increases of 0.16% and 0.14%, respectively. In cases of phosphorus deficiency, both poultry manure and human waste compost were found to be effective in increasing soil phosphorus levels. Moreover, vermicompost and poultry manure were found to enhance the exchangeable potassium levels, with values of 0.467 and 0.432 meq/100 g soil, respectively. Sulfur content was notably higher in plots treated with poultry manure (20.5 ppm), followed by vermicompost (17.87 ppm) and human waste compost (17.21 ppm). Additionally, the treatment with human waste compost exhibited the highest electrical conductivity (243 µs/cm), while poultry manure had the most significant impact on increasing organic matter, showing a substantial 2.76% increment. The study's findings advocate for a transition from chemical fertilizers to compost fertilizers, which would enhance agricultural soil and promote sustainability in both agriculture and the environment.

Keywords: Human waste; Manure; Soil; Nutrition; Composting

Introduction
Over the past four decades, Bangladesh has made significant strides in its efforts to ensure food security for its large population (Islam et al., 2020). Among various approaches aimed at boosting agricultural productivity,

there has been a notable shift in the use of fertilizers and cultivation practices by farmers (Muhie, 2022; Raihan, 2023). Soil organic matter, typically in the range of 2.5% to 3.0%, is a critical factor influencing soil fertility, nutrient availability, and crop yields (Smith & Hughes, 2002). Unfortunately, in Bangladesh, the majority of soils contain less than 1.7% organic matter (Shil et al., 2016). This deficiency in organic matter has hindered soil fertility, posing challenges to crop production throughout the country. Consequently, the supplementation of nutrients in the form of fertilizers has become an integral part of agricultural practices across most of the nation (FAO, 2011). Regrettably, this heavy reliance on inorganic fertilizers has led to a gradual decline in the inherent fertility of the soil over the years (Rahman & Barmon, 2019). For example, the prevalent use of inorganic fertilizers such as NPK has had a significant impact on plant growth, development, and yield (Sanwal et al., 2007). However, excessive NPK application can result in soil infertility, degradation, and contamination of surface and groundwater resources (Onuh et al., 2008). The continuous use of chemical fertilizers like urea can further deteriorate soil properties by causing nutrient imbalances and micronutrient deficiencies (Shukla et al., 2022). The long-term use of chemical fertilizers has also been associated with serious consequences, including soil acidification, imbalanced nutrient levels, disruption of the rhizosphere micro-ecological environment, and altered activity of heavy metal ions in the soil (Lin et al., 2019). Additionally, fertilizer production introduces pollutants into the environment (Rahman et al., 20221; Raihan et al., 2023a), releasing toxic air pollutants and untreated waste into water bodies, leading to environmental pollution (Chandini et al., 2019). In addition to ensuring food production and nutritional security, it is equally crucial to prioritize the preservation of soil health and environmental well-being (Das et al., 2022).

The current global context emphasizes the adoption of eco-friendly agricultural practices for sustainable food production (Raihan et al., 2022; 2023b; 2024). Using organic manure is considered an ecologically sound agricultural practice that not only supports crop production but also enhances biodiversity and soil biological activities (Usman et al., 2016). Organic manure serves as an excellent source of plant-available nutrients and promotes the optimal growth of microbial populations and activities (Bhunia et al., 2021). Numerous studies have highlighted the importance of organic manure as a sustainable and environmentally friendly fertilizer (Han et al., 2016), which improves plant health and productivity (Palm et al., 1997). This recycling process allows nutrients present in organic materials to return to the soil in a form that is readily available for plants (Ahmad et al., 2007). Given the substantial amount of waste materials generated in modern times, the conversion of these materials into organic manure has become a viable option. Organic matter sources such as animal manure, human waste, food waste, yard waste, sewage sludge, and composts have long been recognized in agriculture as beneficial for plant growth, yield, and soil fertility (Pajura, 2024). Composted organic materials contain essential nutrients for plant growth, particularly nitrogen (N) and phosphorus (P) (Beltrán et al., 2006). These organic manures help restore and sustain the inherent properties of the soil, enhance soil biological activities, and potentially increase crop yields without the use of chemicals, making them safe for human consumption (Mrunalini et al., 2022). Organic fertilizers release nutrients slowly, providing a longer-lasting source of nutrition for plants, while inorganic fertilizers release and lose nutrients more rapidly (Han et al., 2016). Properly utilizing organic manure, such as cow dung, human compost, vermicompost, and others, improves soil texture, structure, humus content, color, aeration, water retention capacity, and microbial activity (Chaudhari et al., 2021). With increasing global focus on the environmental impacts of intensive agriculture (Raihan & Tuspekova, 2022), organic manure is recognized as an eco-friendlier alternative. In Bangladesh, urban areas face significant challenges in managing organic waste due to rapid urbanization (Sujauddin et al., 2008). Large-scale composting of urban organic waste could address these issues, reducing waste accumulation and supporting healthy agricultural practices while contributing to a cleaner environment (Almendro-Candel et al., 2019). Among the various organic waste products, dairy manure and poultry waste can serve as valuable components for producing organic manure. Vermicompost, another popular organic manure, contains essential plant nutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B) (Kale et al., 2012), making it a suitable option for Bangladesh. Interestingly, human excreta are also being utilized to create compost manure in Bangladesh, although its use has not yet become widespread. While several studies in Bangladesh have examined the effects of organic composts on crop growth and soil properties, none have explored the potential use of human waste compost as a source of organic nutrients for soil improvement. However, research in other countries has highlighted the richness of human waste compost in essential nutrients, particularly nitrogen (N) and phosphorus (P), which are crucial for plant growth and soil fertility (Häfner et al., 2023; Sanwal et al., 2007). In China, researchers have found that human waste compost can increase crop yields, ensuring both crop quality and soil health (Liu et al., 2021).

The application of toilet compost has been shown to alleviate soil acidification and salinity, underscoring its positive impact on soil chemical properties (Sangare et al., 2015). Additionally, research has demonstrated that the use of treated human excreta can enhance maize crop production and water efficiency in rain-fed agriculture (Guzha et al., 2005). Consequently, this study aims to assess the efficacy of human waste compost in comparison to three others commonly used organic manures in Bangladesh. With these insights in mind, our research endeavors to conduct a comprehensive comparative analysis of the effects of human excreta, cow dung, vermicompost, and poultry manure on the physical and chemical properties of soil, aiming to recommend the most suitable organic manure for enhancing soil quality. Compost enhances soil structure by adding carbon and supplying essential nutrients for plants. Besides serving as a source of essential plant nutrients including nitrogen (N), phosphorus (P), and potassium (K), it enhances the physico-chemical and biological characteristics of the soil. Compost serves as a vital fertilizer by enhancing soil health and production, mitigating greenhouse gas emissions, and generating social and economic advantages. The research on compost fertilizer is significant due to its potential to enhance soil health, decrease waste, and alleviate climate change. The study's findings support a shift from chemical fertilizers to compost fertilizers, which would improve agricultural soil and foster sustainability in agriculture and the environment.

Materials and Methods

Study area and soil properties

The experiment took place between January 2021 and March 2021, consisting of two distinct parts of Bangladesh. The first part of the experiment primarily focused on the effects of organic amendments on soil quality improvement, while the second part, which pertains to the impact of these amendments on the growth of red amaranth, will be addressed separately in another paper.The research site was situated in a subtropical climate region characterized by moderately high temperatures, humidity, and substantial rainfall during the Kharif season (April to September), with intermittent strong winds. In contrast, the Rabi season (October to February) was marked by limited rainfall and relatively cooler temperatures. The site fell within the agroecological zone (AEZ-9) of the Old Brahmaputra Floodplains, characterized by non-calcareous dark grey floodplain soil, as per the classification by the Food and Agriculture Organization (FAO, 2001).

Further details regarding the soil characteristics will be explored below:

Table 1. Soil Properties of the experimental field

Characters		Definition/Value
Location		Environmental Science Field Laboratory, Bangladesh Agricultural University, Mymensingh, 24°75´ N Latitude and 90°50´ E longitude
Morphology	Land type	Medium high land, an elevation of 18 m above the sea level
	General soil type	Non-calcareous Dark Grey Floodplain Soil
	Parent materials	Old Brahmaputra river-borne deposits
	Soil series	Sonatola
	Drainage	Poor drainage system
	Flood level	Above flood level
	Topography	Fairly leveled
	Vegetation	Rice crop is grown year-round
Physical properties	Textural classes	Silty loam
	Soil moisture	24.80%
	Sand	30.24%
	Silt	58%
	Clay	11.75%
Chemical properties	Soil pH	6.57
	Total Nitrogen	0.10%
	Available Phosphorus	6.20 ppm
	Exchangeable Potassium	0.142 me/ 100 g soil
	Organic matter content	1.15%
	Organic Carbon	1.20%

Source: Department of Soil Science, Bangladesh Agricultural University, Mymensingh, 2021

Experimental design

The experiment was conducted following a Randomized Complete Block Design (RCBD) with three replications. A total of 15 plots, each measuring 2 m × 2 m, were arranged, maintaining a 0.5 m separation between blocks and between individual plots. The assignment of all experiment treatments to the unit plots within each replication was done randomly.

The field experiment comprised five distinct treatments, each designated as follows: Control (T0), Vermicompost (T1), Human Waste Compost (T2), Poultry Manure (T3), and Cow Dung (T4). The nutritional characteristics of these fertilizers, along with the corresponding application rates per plot, are detailed in Table 2.

Table 2: Summary of the treatments applied in the experimental plots

	Definition	% N	% P	% K	
T0	Control (no fertilizer)				No fertilizer
T1	Vermicompost	1.48	0.67	0.94	4 kg
T2	Human waste compost	1.23	0.86	0.31	5 kg
T3	Poultry Manure	1.52	0.62	0.53	4 kg
T4	Cow dung	0.73	0.38	0.26	8 kg

Experimental procedures

Land preparation

The experimental plot was prepared through a series of steps. Initially, it was opened using a country plow, followed by plowing and cross-plowing, which were repeated up to five times. Subsequently, laddering was carried out at appropriate intervals to ensure that the plot was finely pulverized and well-prepared. Throughout the land preparation process, any weeds and remnants from previous crops were diligently collected and cleared from the area to achieve optimal soil tilth conditions

Application of organic amendments

All of the vermicompost, human waste compost, cow dung, and poultry manure were applied during the final stage of land preparation. The quantity of compost needed for each plot was determined according to the plot's area. Following the application of composts, the land was left undisturbed for approximately one month to allow for the gradual and natural integration of the compost materials with the soil.

Collection of soil sample

Soil samples were collected post-harvest from the experimental field using an auger. Samples were taken from five distinct locations within each experimental plot, reaching a depth of 0-5 cm. These individual samples were then meticulously combined to create a composite soil sample

Soil analysis

Upon gathering the soil samples, any extraneous materials such as rocks, plant roots, leaves, and other debris were meticulously removed. Subsequently, the samples were air-dried, thoroughly mixed, and ground until they could pass through a sieve. The processed soil samples were then stored in clean plastic bags, ready for subsequent mechanical and chemical analyses

The chemical analysis of the soil samples was conducted at the Soil Science Department of BAU (Bangladesh Agricultural University), Mymensingh. The analysis encompassed various soil properties, including soil texture, pH levels, electrical conductivity (EC), organic matter content, total nitrogen (N), availability of phosphorus (P) and sulfur (S), as well as the levels of exchangeable potassium (K) and exchangeable sodium (Na).

The particle size distribution of the soil was determined using the hydrometer method outlined by Piper (1965). The textural class of the soil was determined by plotting the percentages of sand, silt, and clay on Marshall's triangular coordinate diagram, following the USDA system.

Soil p^H was measured with the help of a glass electrode p^H meter using a water suspension of 1:2:5 as described by Jackson (1962). Besides, soil pH levels were measured using a glass electrode pH meter. A water suspension of soil at a ratio of 1:2:5 was prepared, as described by Jackson (1962). Organic matter content in the soil was determined using the wet oxidation method developed by Walkley and Black (1934). This method involves oxidizing organic matter with an excess of K2Cr2O7 solution in the presence of FeSO4. The organic matter content was calculated by multiplying the organic carbon amount by the Van Bemmelen factor of 1.73 and expressed as a percentage. Nitrogen content in the soil was estimated using the micro-Kjeldahl method. In this method, the soil was digested with a mixture of 30% H_2O, concentrated H_2SO_4, and a catalyst blend of K_2SO_4:$CuSO_4$:Se powder in a specific ratio (100:10:1). Nitrogen in the digest was determined by distillation with 40% NaOH, followed by titration of the distillate with 0.1 N H_2SO_4 (Page et al., 1989). Available phosphorus was extracted from the soil by shaking it with a 0.5 M $NaHCO_3$ solution at pH 8.5, following the method of Olsen (1954). The phosphorus content in the extract was determined by developing a blue color through $SnCl_2$ reduction of phosphomolybdate complex solution and measuring it with a spectrophotometer. Available P was calculated using a standard curve.

Flame emission spectrometry (FES) and flame atomic absorption spectrometry were used to determine the levels of exchangeable bases such as potassium and sodium extracted from soil by leaching with ammonium acetate solution. The cation content in the leachate was analyzed by FES. The air-dried soil sample was weighed, packed into a sample extraction setup, and extracted by leaching with 4x50 ml ammonium acetate solution. The leachate was collected in a 250 ml volumetric flask, diluted to 250 ml with double reverse osmosis water, and analyzed for exchangeable K using FES and exchangeable Na using atomic absorption spectrometry. Available sulfur content in the soil was determined by extracting soil samples with a 0.15% CaCl2 solution, as described by Page et al. (1989). The sulfur content in the extract was measured turbidimetrically using BaCl2 and an acid solution, with spectrophotometry at a wavelength of 420 nm.

Statistical analysis

Following the analysis of all physiological and chemical parameters of the soil, analyses of variance (ANOVA) were conducted to assess the influence of the different manures on these parameters. The statistical analysis was performed using the R software, which is well-suited for conducting ANOVA and other statistical tests to determine significant differences and relationships in data.

Results and Discussion

The well-decomposed cow dung, poultry manure, vermicompost, and human waste compost were applied and thoroughly incorporated into the soil as necessitated by the experimental requirements. Additionally, intercultural operations were carried out as needed throughout the experiment to maintain the crop's growth and health.

Effect of organic amendments on soil properties

Soil texture

The soil analysis revealed that, on average, the sand content was 24.4%, silt content was 60.8%, and clay content was 14.8% (as depicted in Figure 1). These results indicate that the textural class of the study area ranged from silty loam to loam. The vertical bar in the figure represents the standard deviation. These findings are consistent with those reported by Kale et al. (2012) in their assessment of the effects of organic residue compost on the development of soil physicochemical characteristics. Silty soil is characterized by a fine, powdery texture and is known for its high fertility. Soil with a healthy structure feels crumbly to the touch and provides ample space for air, water, and energy to move freely.

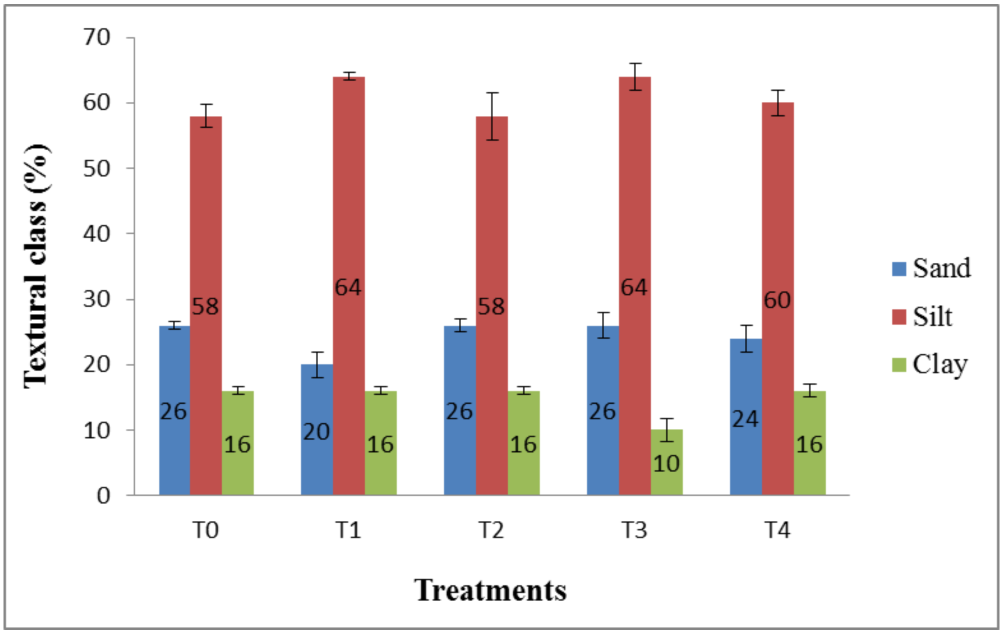

Figure 1. Influence of organic amendments on soil textural class

Soil pH

The average pH values of the soil after harvest were measured to be 6.77, 6.88, 6.73, 6.61, and 6.53, each influenced by the application of different treatments (Figure 2). The vertical bars in the figure represent the standard deviation. Significant variations in pH values were observed, particularly in treatments T1, T3, and T4, at a significant level of 5%.

The highest pH value (6.88) was recorded in the plot treated with vermicompost (T4), while the lowest pH value (6.53) was observed in the plot treated with cow dung (T4). The numerical order of decreasing soil pH, from highest to lowest, was T1 < T0 < T2 < T3 < T4. It's worth noting that the application of organic composts appeared to lead to a decrease in soil pH within a span of 1 to 2 months, likely due to the release of acids during the decomposition process.

These observations align with findings from Tester (2017) and Whalen et al., (2000), who noted that the addition of organic composts could improve soil pH and electrical conductivity. Additionally, Adeniyan and Ojeniyi (2005) reported that the application of organic composts had positive effects on soil pH, salt content, and macronutrient concentrations in the soil.

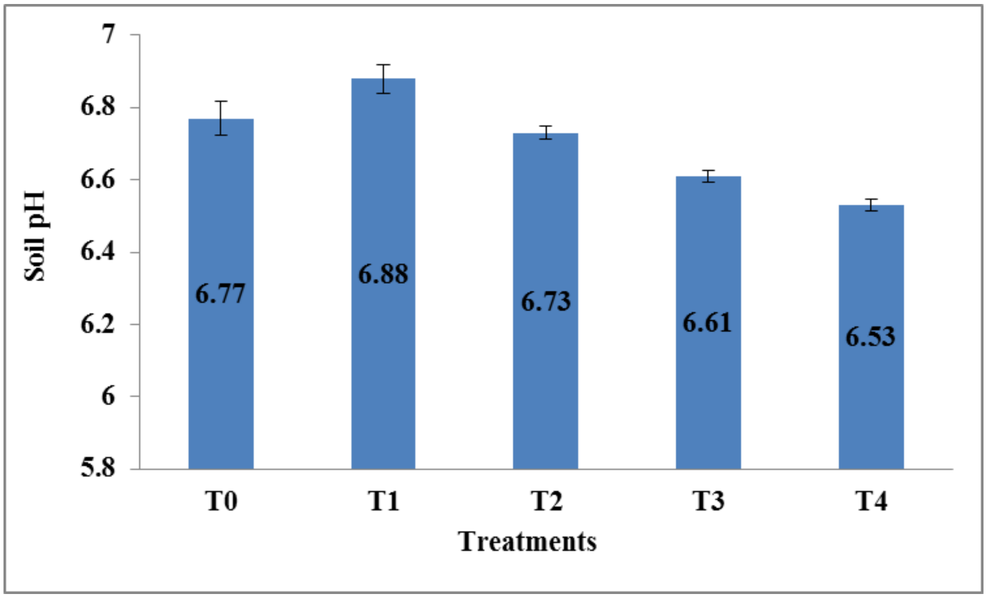

Figure 2. Influence of organic amendments on soil pH

Electrical conductivity

The average electrical conductivity (EC) values for different treatments were recorded as follows: T0 (control) - 189 µs/cm, T1 (vermicompost) - 203 µs/cm, T2 (human waste compost) - 243 µs/cm, T3 (poultry manure) - 229 µs/cm, and T4 (cow dung) - 208 µs/cm (as illustrated in Figure 3). The vertical bars in the figure represent the standard deviation. Notably, the soil EC values were higher in all treatments compared to the control (T0).
The highest EC value (243 µs/cm) was observed in the T2 treatment (human waste compost), while the lowest EC value (189 µs/cm) was recorded in the control (T0). The increase in EC can likely be attributed to the mobility of ions, their valences, and their relative concentrations. This observation aligns with the findings of Islam et al. (2011), who reported an improvement in soil electrical conductivity with the application of organic manures. Similarly, Kale et al. (2012) noted an increase in electrical conductivity following the application of organic fertilizer.

Organic matter

The average organic matter (OM) content in the soil after harvest varied across treatments, with values of 1.15% for T0 (Control), 2.35% for T1 (vermicompost), 1.98% for T2 (human waste compost), 2.69% for T3 (poultry manure), and 1.73% for T4 (cow dung) (as shown in Figure 4). The vertical bars in the figure represent the standard deviation. Significantly, the OM content displayed variations as influenced by the different treatments at a significance level of 5% (as indicated in Table 3). The soil's organic matter content ranged from 1.15% to 2.69% after harvesting the crops, with the highest value (2.69%) recorded in the poultry manure treatment (T3) and the lowest in the control treatment (T0). This increase in organic matter content aligns with the findings of previous research. Islam et al. (2011) and Tester (2017) both reported significant increases in soil organic matter content following the application of organic manure. Additionally, Allen and Zink (2008) noted an increase in organic matter levels in the soil after the application of farmyard manure and green manure.

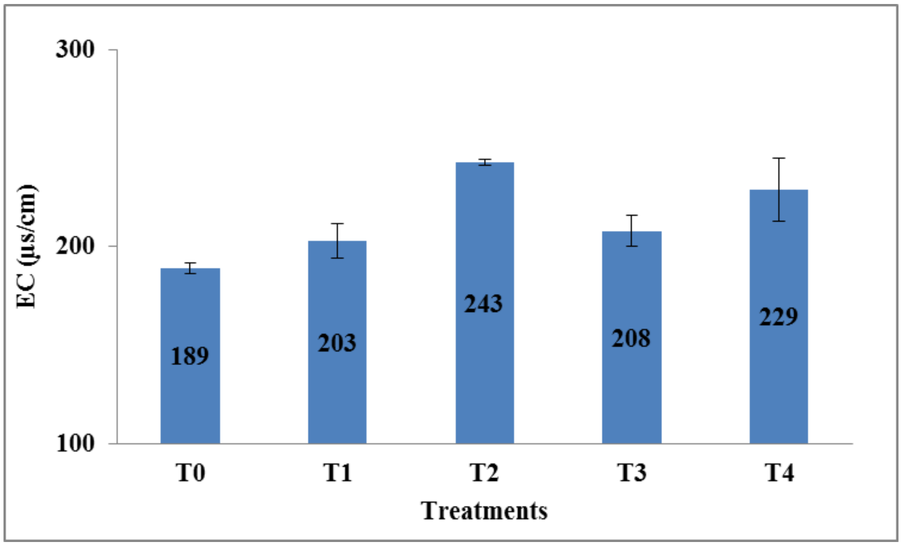

Figure 3. Influence of organic amendments on electrical conductivity (EC)

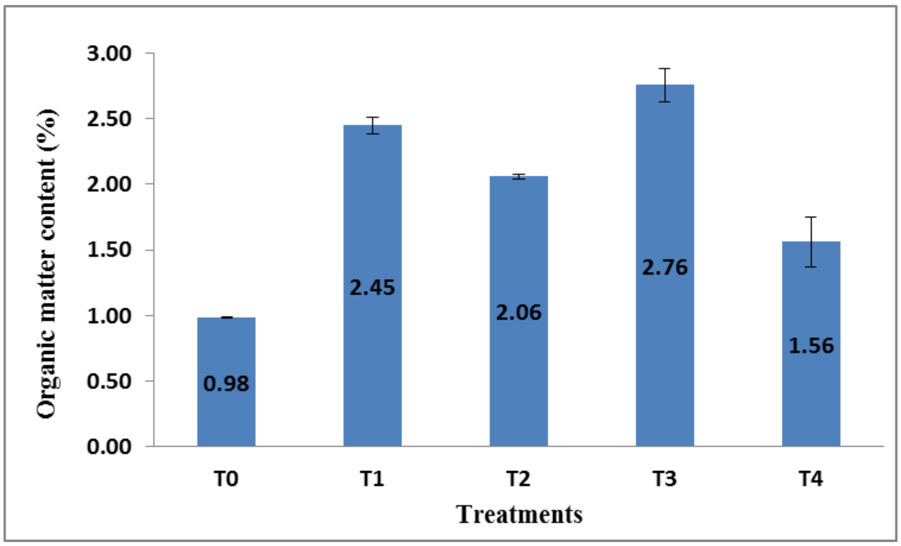

Figure 4. Influence of organic amendments on the organic matter content

Total nitrogen

In the post-harvest soil, the average nitrogen (N) content varied across treatments, with values of 0.084% for T0 (Control), 0.127% for T1 (vermicompost), 0.139% for T2 (human waste compost), 0.145% for T3 (poultry manure), and 0.118% for T4 (cow dung) (as depicted in Figure 5). The highest N content (0.145%) was observed in the plot where poultry manure was applied (T3), while the lowest value (0.084%) was found in the control (T0). The vertical bars in the figure represent the standard deviation.

These results suggest that the application of organic manures contributed to higher total N concentrations in the soil compared to the control. This aligns with the findings of various researchers, including Havlin et al. (2012), Khatik and Dikshit (2001), and Ojeniyi (2008), who reported that the use of organic manure increased total N concentrations in the soil. Furthermore, Kashem et al. (2015) noted that vermicompost had higher available N and P contents in the soil compared to other treatments.

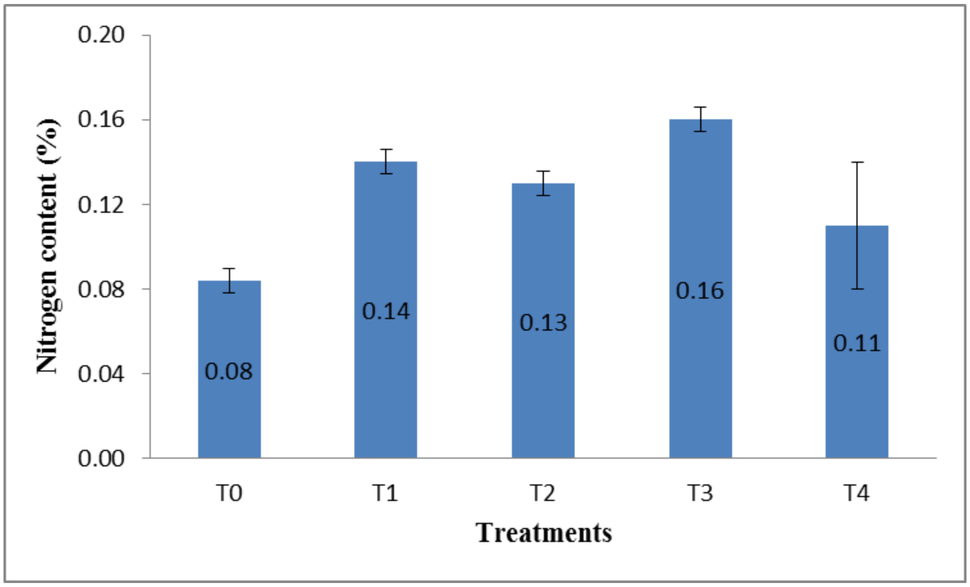

Figure 5. Influence of organic amendments on nitrogen content

Available phosphorus

The average phosphorus (P) content in the post-harvest soil varied among treatments, with values of 6.19 ppm for T0 (Control), 8.66 ppm for T1 (vermicompost), 6.54 ppm for T2 (human waste compost), 6.96 ppm for T3 (poultry manure), and 6.49 ppm for T4 (cow dung) (as illustrated in Figure 6). The available P content in the soil ranged from 6.19 ppm (T0) to 8.66 ppm (T1). The vertical bars in the figure represent the standard deviation. Significant variations in available P content were observed in the T2 and T3 treatments at a 5% significance level (as indicated in Table 3).

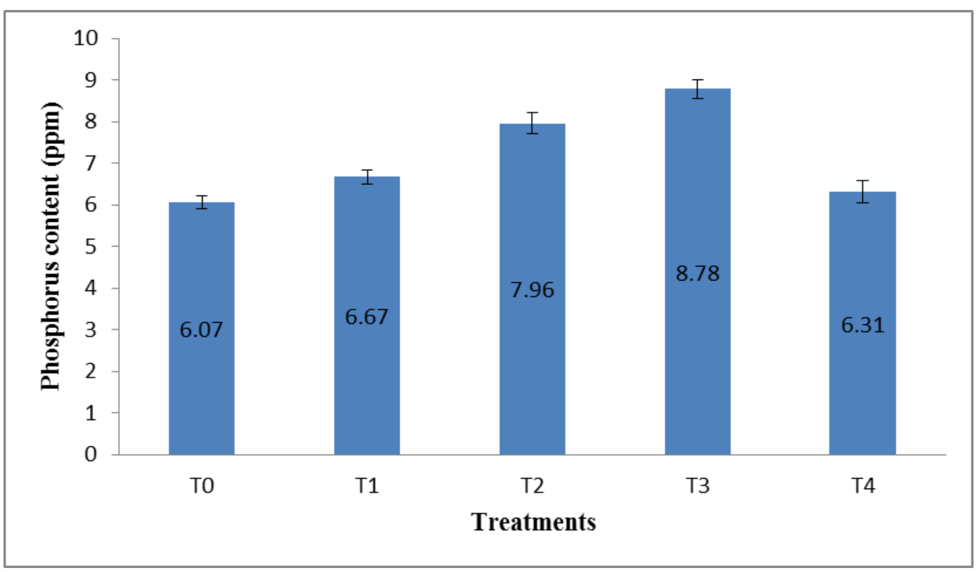

Figure 6. Influence of organic amendments on phosphorus content

Soils treated with organic manures exhibited higher levels of available P compared to the control. This increase in available P is likely due to the release of more P during the decomposition of organic manure. These findings are consistent with the reports of Onuh et al. (2008) and Rahman et al. (2014), which suggested that the application of organic manures can enhance available P content in the soil.

Exchangeable potassium

In the post-harvest soil, the average potassium (K) content varied among treatments, with values of 0.144 meq/100g for T0 (Control), 0.467 meq/100g for T1 (vermicompost), 0.352 meq/100g for T2 (human waste compost), 0.438 meq/100g for T3 (poultry manure), and 0.313 meq/100g for T4 (cow dung) (as shown in Figure 7). The vertical bars in the figure represent the standard deviation. These results indicate significant variations in K content across the different treatments.
Organic manure treatments, particularly vermicompost (T1) and poultry manure (T3), resulted in higher K content in the soil compared to the control (T0). These findings suggest that the application of organic manures can increase the K content in the soil.

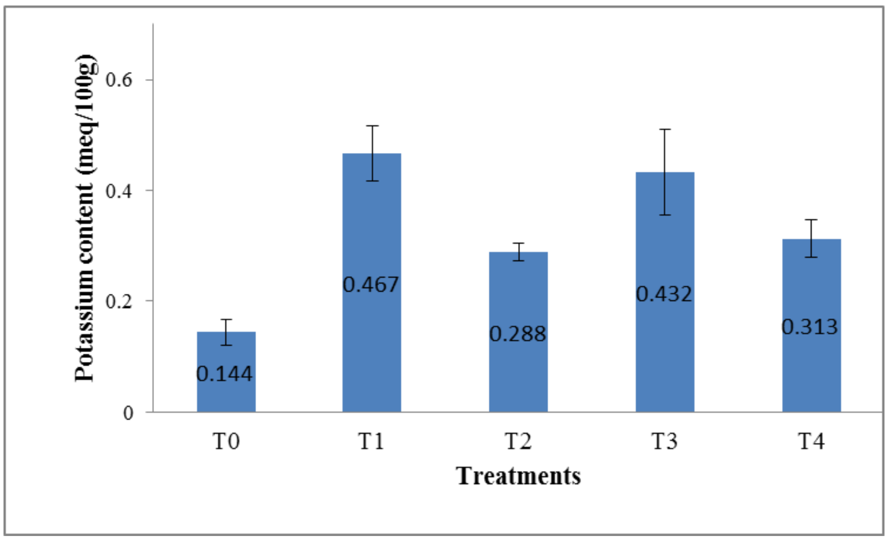

Figure 7. Influence of organic amendments on potassium content

The highest exchangeable potassium (K) content was observed in soils treated with vermicompost (T1), while the lowest exchangeable K content was found in the control (T0). These results suggest that the application of organic manures, particularly vermicompost, led to higher levels of exchangeable K in the soil compared to the control. This aligns with previous research findings, such as those reported by Ouédraogo et al. (2001), which showed that the significant effect of organic manures improved exchangeable K levels in the soil. Similar results have also been reported by other studies, including Ojeniyi (2008), Onuh et al. (2008), and Palm et al. (1997).

Exchangeable sodium

In the post-harvest soil, the average sodium (Na) content varied among treatments, with values of 0.956 meq/100g for T0 (Control), 2.63 meq/100g for T1 (vermicompost), 3.13 meq/100g for T2 (human waste

compost), 3.36 meq/100g for T3 (poultry manure), and 2.87 meq/100g for T4 (cow dung) (as shown in Figure 8). The vertical bars in the figure represent the standard deviation.
The highest exchangeable Na content was obtained from the poultry manure treatment (T3), while the lowest exchangeable Na content was found in the control (T0). These results indicate that exchangeable Na content was higher in soils treated with organic manures compared to the control. This finding aligns with the results reported by M. Rahman et al. (2014), who found that the application of organic manures increased the total nitrogen, potassium, magnesium, and sodium content in the soil.

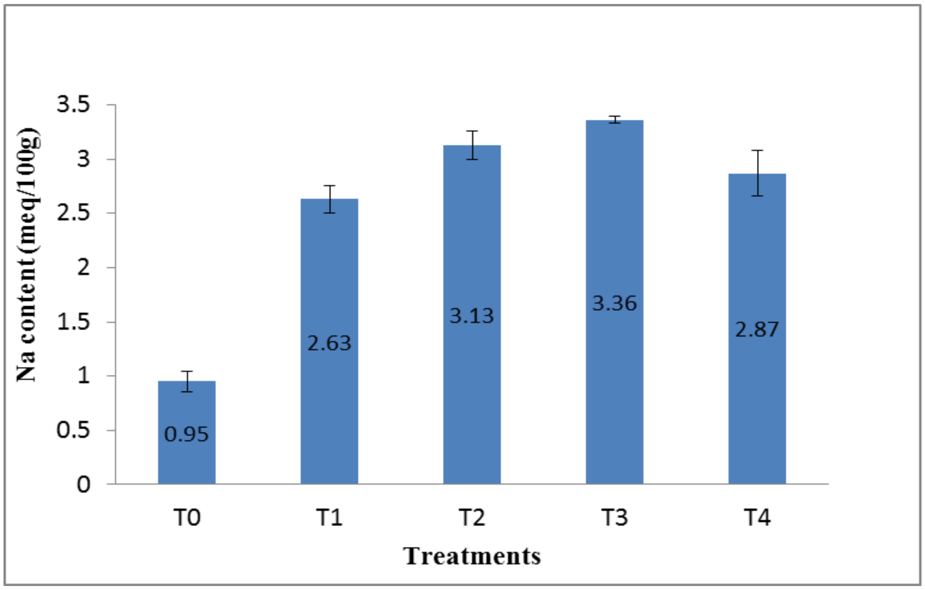

Figure 8. Influence of organic amendments on sodium (Na) content

Available sulphur

The average sulfur (S) content in post-harvest soil varied among treatments, with values of 10.42 ppm for T0 (Control), 17.87 ppm for T1 (vermicompost), 17.21 ppm for T2 (human waste compost), 20.5 ppm for T3 (poultry manure), and 15.74 ppm for T4 (cow dung) (as shown in Figure 9). The vertical bars in the figure represent the standard deviation. The sulfur content in the soil did not differ significantly among the different treatments at the 5% significance level (as indicated in Table 3). The highest S content was obtained in the poultry manure treatment (T3), while the lowest S content was found in the control (T0). Soils treated with organic manures showed higher values of available S compared to the control. This increase in available S in organic manure-treated soils may be attributed to the release of more available S during the decomposition of organic manure. Similar findings were reported by M. Rahman et al. (2014), who found that organic composts increased the sulfur content in the soil.

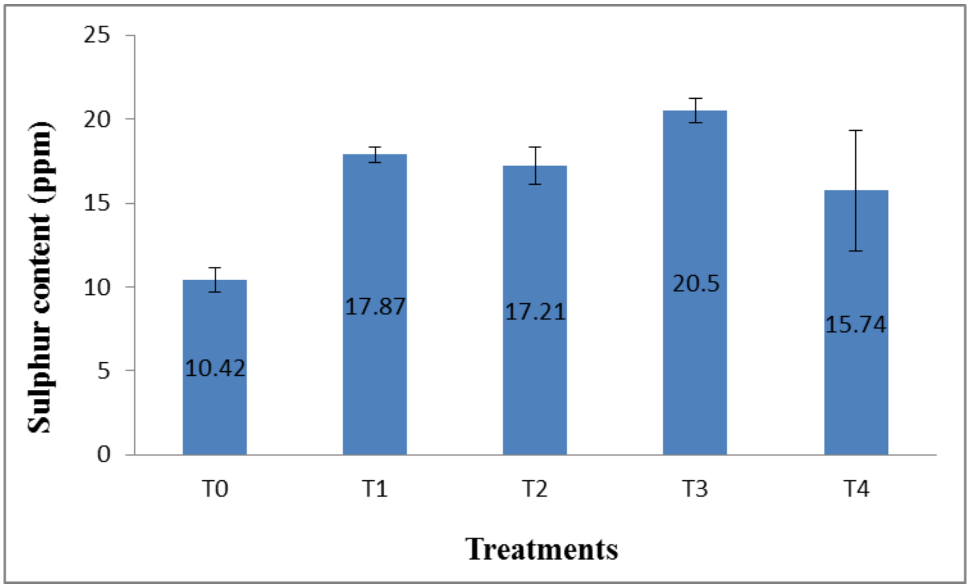

Figure 9. Influence of organic amendments on sulfur content

Table 3. Effect of organic amendments on soil properties at the end of the experiment

	Treatments					
	T_0	T_1	T_2	T_3	T_4	
pH	6.77 b	6.88 a	6.73 b	6.61 c	6.53 d	*
Electrical conductivity (μs/cm)	189 c	202.67 bc	243 a	208 b	229 a	*
Organic matter (%)	0.98 e	2.45 b	2.06 c	2.76 a	1.56 d	*
Total N (%)	0.08 c	0.14 ab	0.13 b	0.16 a	0.11 b	*
Available P (ppm)	6.17 d	6.67 c	7.96 b	8.78 a	6.31 cd	*
Exchangeable K (Meq/100g)	0.14 c	0.46 a	0.28 b	0.43 a	0.31 b	*
Exchangeable Na (Meq/100g)	0.95 c	2.63 b	3.13 a	3.36 a	2.87 b	*
Available S (ppm)	10.42 c	17.80 ab	17.21 b	20.56 a	15.74 b	*
Sand	26.33 a	20 b	26 a	26 a	24 a	*
Silt	58 b	63 a	58 b	64 a	60 ab	*
Clay	15.67 a	16.33 a	15.67 a	10 b	16 a	*

Note: * = 5% level of significance, in the case of soil properties, the column having a common letter (s) do not differ significantly at 5% level; Here, T_0 = no fertilizer, T_1 = vermicompost, T_2 =human waste compost, T_3 = poultry manure, T_4 = cow dung

Conclusion

This study aims to evaluate the effectiveness of human waste compost relative to poultry manure, cow dung, and vermicompost in Bangladesh. The experimental design included a Randomized Complete Block Design. The results and discussion clearly demonstrate the significant improvement in soil quality with the application of organic manures. Poultry manure and vermicompost had the most substantial positive effects on total nitrogen, with increases of 0.16% and 0.14%, respectively. In cases of phosphorus deficiency, poultry manure and human waste compost were effective in increasing soil phosphorus levels, with values of 8.78 and 7.96 ppm, respectively. Vermicompost and poultry manure enhanced exchangeable potassium, with values of 0.467

and 0.432 meq/100 g of soil, respectively. Sulfur content was notably higher in plots treated with poultry manure (20.5 ppm), followed by vermicompost (17.87 ppm) and human waste compost (17.21 ppm). The highest electrical conductivity was observed in the human waste compost treatment (243 µs/cm). Poultry manure had the most substantial impact on increasing organic matter, with a 2.76% increment.
The study's findings advocate for a transition from chemical fertilizers to compost fertilizers, which would enhance agricultural soil and promote sustainability in both agriculture and the environment. However, the choice of organic manure should depend on specific soil nutrient deficits. For example, if there is a phosphorus deficiency in the soil, poultry manure and human waste compost may be the best options for achieving optimal results. Encouraging farmers to use organic amendments in agriculture can help maintain soil quality, improve crop yields, and contribute to environmental sustainability. Further experiments with varietal trials in different regions of Bangladesh are recommended to explore the effectiveness of various organic amendments compared to conventional practices.

Declaration

Acknowledgment: Not applicable.

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Conflict of interest: The authors declare no conflict of interest.

Ethics approval/declaration: Not applicable.

Consent to participate: Not applicable.

Consent for publication: Not applicable.

Data availability: The data that support the findings of this study are available on request from the authors.

Authors contribution: Samanta Islam contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Samanta Islam and Asif Raihan. All authors read and approved the final manuscript.

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RESEARCH ARTICLE

Quantitative Ethnobotany of the Plants of District Swabi, Tehsil Razar, Khyber Pakhtunkhwa, Pakistan

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Abstract
The present study presents first tentative attempt to determine the quantitative ethnobotanical profile of plants of Tehsil Razar, District Swabi. Relative frequency citation (RFC) and Use value (UV) of plant resources were calculated. Pearson correlation coefficient (PCC) was calculated to find any significance between RFC and UV. A total of 60 plants from 37 families had ethnobotanical importance in the investigated area. It included 1 pteridophyte, 13 monocots and 46 dicots. Quantitative results showed that 24 species with the highest RFC value of 1, were important in the area in terms of their uses. *Acacia modesta*, *Acacia nilotica sub sp. nilotica* and *Ailanthus altissima* were popular and common medicinal plants in the study area with highest use value of 6.07, 5.60 and 3.40 respectively. The Pearson correlation coefficient (PCC) between RFC and UV was 0.01 with P value well below than 1% which demonstrate a highly significant correlation between RFC and UV.

Keywords: Quantitative ethnobotany; Pearson correlation; Swabi; Razar

Introduction

Plant species have long played important roles for humanity. The formal study of these plants has proven to be a powerful tool in understanding how different indigenous communities relate to natural resources, notably for medical and pharmaceutical applications (de Albuquerque and Hanazaki, 2009). Ethnobotany is a multidisciplinary science which is defined as the relation between plants and people. It explores the usage of plants in every aspect of life (Shinwari, 2010). Indeed, ethnomedicinal study has been a fundamental source for the discovery of natural and synthetic drugs (Fabricant and Farnsworth, 2001). Ethnobotanical knowledge continues to provide a starting point for many successful drug screening projects in recent years (Heinrich and Bremner,2006). The increased dependence of anthropogenic activities over the plants may also lead to alarming situation in vegetation. The link between plants and human cultures is not restricted to the use of plants for food, clothing and shelter but also includes their use for religious ceremonies, ornamentation, health care and sports (Schultes, 1992). Ethnobotany is important in the production of modern drugs by exploring the traditional usage of locally important plants. Wild resources of medicinal plants had been used by the native people since time immemorial in conventional healing systems (Adnan et al., 2014). According to data from the World Health Organization (WHO), about 80% of the world's population, especially the rural people of developing countries, still primarily rely on traditional medicines (Islam, 2006). On the other hand, the origins of over 50% of all pharmaceutical drugs could be traced back to ethnomedicine (Van Wyk et al., 1997) District Swabi is located between 34°7' N 72°28' E. It is bounded in the north by District Buner, on the east by District Haripur, in the south by District Attock and on the west by District Nowshera and Mardan (Fig. 1). The altitude varies from 300 to 650 meters having average elevation about 321m (Khan, 2009; Hussain et al., 1993). There are four Tehsils in District Swabi namely: Topi, Swabi, Lahor and Razar. Tehsil Razar was established on 10th September, 2009. It is located between 34°14' N and 72°20' E. About 90% population depends on agriculture and utilizes maximum land for this purpose. Tehsil Razar has extreme climate. Temperature rises sharply in the months of May and June that remains almost persistent during the months of July, August and September. Maximum temperature is observed during the month of June which is 41.5°C. The minimum temperature of 2°C is recorded in the month of January. A number of ethnobotanical studies have been conducted in Pakistan to strengthen the prevailing ethnobotanical knowledge. Barkatullah et al. (2009) assessed 100 plants distributed over 49 families from Charkotli Hills, Batkhela District, Malakand, Pakistan. Sher et al. (2011) collected ethnobotanical knowledge of 216 plant species belonging to 87 families from Chagharzai Valley, District Buner, Pakistan. Hadi et al. (2013) conducted ethnobotanical survey at Rech Valley, District Chitral, Hindu-Kush range, Pakistan. Khan et al. (2015 a) documented ethnoveterinary medicinal plant for curing various animal diseases in District Peshawar. Khan et al. (2015 b) explored ethnobotanical knowledge of Tehsil Barawal, District Dir (Upper). Ali et al. (2015) gathered the ethnobotanical knowledge about 86 plant species of Mahaban and Malka of District Buner. Qasim et al. (2015) reported 24 ethnomedicinal plants from Swabi, Pakistan. Adequate documentation of such knowledge, and especially of traditional ethnomedicinal practices, is important because ethnomedicinal healers have a long association with herbs and their medicinal properties (Kabir et al., 2014). Notably, ethnomedicinal knowledge is usually passed verbally from one generation to the next through family members (Nadembega et al., 2011), and most of this knowledge has not been formally documented (Asase et al., 2008). However, in recent years, there has been a continuous decline in traditional medicinal practices, because of reduced interest in the younger generation toward traditional treatment systems, coupled with rural depopulation, mass deforestation, and migrations of traditional medicinal healers to other jobs. These factors have contributed to the rapid loss of this rich knowledge (Kadir et al., 2013). In contrast, ethnomedicinal research has gained interest among the scientific community (Heinrich, 2000).

However the review of literature suggests that there is no work done in Tehsil Razar on the exploration of quantitative ethnobotanical information. Therefore, the present work is aimed to classify plants ethnobotanically on quantitative basis.

Materials and method

Study Area

Razzar is a Tehsil located in Swabi District, Khyber Pakhtunkhwa, Pakistan. Its administrative seat is located in Shewa Adda near Kalu Khan. At Latitude of 34.21398234406986 and Longitude of 72.31581968961575. It consists of different villages and union councils, including, Sheikh Jana ,Yaqubi, Yar Hussain, Sudhir, Sardcheena, Babo Dehri, Dobian, Kalukhan, Shewa, Kernal Sher Kallay (Naudeh), Adina, Ismaila, Turlandi, Naranji, and Farmoli.Villages Dagai,Taraki and Rashaki are also parts of Razzar Tehsil. The name Razzar is based on the forefather of razzar clan of mandhanr tribe mubarak khan razzar.

Plant Collection, Identification, and Preservation

Ethnobotanical uses from 20 villages of Tehsil Razar were reported. Plant specimens were collected, preserved and mounted properly on standard herbarium sheets. Identification of plant was done through flora of Pakistan.

Field Study and Data Collection

In each village interviews were carried out with respondents and informants including farmers, herbalists, shepherds, pansaries (medicinal plant sellers), and elders including both male and females old over 45 years. Each village was visited in summer, winter and spring season in order to record diverse ethnobotanical information of the area. Ethnobotanical information were quantitatively computed by using frequency citation (FC), relative frequency citation (RFC) and use value (UV) along with Pearson correlation coefficient (PCC) following Bano et al. (2014).

Relative frequency citation (RFC)

RFC demonstrates the local importance of the species. It is calculated by dividing frequency of citation (FC, the number of informants mentioning the use of the species) to the total number of participated informants.

$RFC = FC/N \ (0 < RFC < 1)$

Use value

The Use Value (UV) shows the relative importance of locally known plants. It was calculated as follows:

$$UV=\sum Ui/N$$

Where Ui is the number of uses mentioned by each informant for a particular species and N is the total number of informants.

Pearson correlation coefficient

It represents the linear relationship between two numerically quantified variables. It is the ratio of the covariance between two variables to their standard deviations. It is calculated as follows:

$$r = \frac{COV(X,Y)}{SD(X) \times SD(Y)}$$

Where r is the Pearson correlation coefficient, COV is the covariance, X and Y are the variables for which the relationships is going to explore and SD is the standard deviation for the same variables.

Result and Discussion

Demography of Informants

A total of 170 informants were interviewed. Out of these, 129 were male and 41 were female.

Documented Plant Species and Their Taxonomy

The ethnobotanical survey identified 60 plant species from 37 families, there were 35 herb species, 18 tree species and 6 shrub species (Fig. 4) demonstrating the rich plant biodiversity of the region. Similar findings have been reported in ethnobotanical studies conducted in various regions, highlighting the role of diverse flora in traditional knowledge systems (Abbasi et al., 2022; Ghorbani et al., 2021). The dominance of dicots (46) over monocots (13) and pteridophyte (1) aligns with global trends in ethnobotanical inventories, as dicotyledonous species typically constitute the majority of ethnobotanically significant plants (Sharma et al., 2020) (Table. 3). The dominance of the Poaceae family, with 10 species, is consistent with its wide ecological adaptability and economic importance globally (Kaur et al., 2021). Families like Amaranthaceae (4), Mimosaceae, Euphorbiaceae, and Asteraceae, 3 species each. Rest of families had 2 or less species, are commonly reported in ethnobotanical studies due to their high utility in traditional medicine and other practices (Kumar et al., 2019). The presence of families with fewer species but significant uses, such as those contributing to construction, fuel, and medicinal applications, indicates the functional diversity of plant species in rural livelihoods (Bibi et al., 2023). The multifunctionality of plants identified in the study resonates with similar findings from rural and indigenous communities worldwide. Medicinal uses 35 (58.33%) dominated, reflecting the heavy reliance on traditional herbal remedies in regions with limited access to modern healthcare facilities (Iqbal et al., 2023). Fodder Twenty six species (41.67%), fuelwood Sixteen species (26.67%), and other uses such as construction, furniture, and edible applications, underline the integrative role of plant resources in subsistence economies (Ahmad et al., 2021). Thirteen species (21.67%) were utilized as construction and building materials, reflecting their importance in traditional architecture and rural livelihoods. Similar studies in other regions have reported the use of species such as *Acacia modesta* and *Acacia nilotica* in construction due to their durable wood and resistance to pests (Sharma et al., 2020; Ahmad et al., 2022). These species have been historically preferred for constructing homes, fences, and agricultural tools. The use of 12 species (20%) for furniture-making is consistent with traditional practices, where locally available timber species are prioritized for their affordability and sustainability. Species like *Morus alba* and *Ailanthus altissima* are commonly documented in ethnobotanical research for their sturdy wood, which is used to craft furniture, agricultural implements, and other household items (Kumar et al., 2021). The identification of 12 edible species (20%) emphasizes the role of wild plants in local diets, particularly in rural and semi-urban areas. Edible plants, including fruits, leaves, and seeds, often serve as supplementary food sources, particularly during times of food scarcity. For instance, *Morus alba* is widely recognized for its edible fruits and leaves used as fodder (Abbasi et al., 2022). Fourteen species were noted for their use in making hedges, mats, ropes, miswak (tooth-cleaning sticks), and dyes. These uses underscore the ingenuity of local communities in utilizing plant materials for daily needs. For example, *Acacia nilotica* is traditionally used for making ropes and hedges, while its bark and pods are sources of tannins for dye production (Bibi et al., 2023). Such practices demonstrate the role of ethnobotanical knowledge in resource optimization and reducing reliance on synthetic materials. Only three species were identified as having ornamental value, suggesting that the primary focus of plant use in the area is utilitarian rather than aesthetic. This aligns with findings from similar rural contexts where ornamental use is secondary to subsistence needs (Choudhary et al., 2023). Species such as *Acacia modesta*, *Acacia nilotica subsp. nilotica*, *Morus alba*, and *Ailanthus altissima* were noted for their multiple uses. These species are not only crucial for construction and furniture-making but also serve as sources of fuelwood, fodder, and medicine. The multifunctionality of these species highlights their ecological and economic importance in rural systems. Studies by Ahmed et al. (2021) and Hussain et al. (2023) similarly emphasize the critical role of multipurpose trees in meeting the diverse needs of local communities while supporting sustainable resource management. *Acacia modesta, Acacia nilotica subsp. nilotica,* and *Ailanthus altissima emerged* as the most valued species, consistent with their widespread use in ethnobotanical and agroforestry systems. These species' high use values (UV) and relative frequency of citation (RFC) suggest their cultural and practical importance (Sahoo et al., 2020). Their multifunctionality across categories such as medicine, construction, and fuelwood has been documented in similar contexts, reaffirming their role in rural resource management (Hussain et al., 2023).

Table 1. Frequency citation (FC), relative frequency of citation (RFC) and use value (UV) of ethnobotanical plants of Tehsil Razar, Swabi

S.No.	Voucher No.	Botanical Name	FC	RFC	∑Ui	UV	Part used	Uses
1.	HBKU-423	*Acacia modesta* Wall.	15	1.00	91	6.07	Gum, wood, leaves and roots	Tonic, healing agent, pain killer, use in cough, jaundice, backache, fodder, furniture, building, hedges and miswak
2.	HBKU-424	*Acacia nilotica sub sp. nilotica* (L.) Delile	15	1.00	84	5.60	Gum, wood and leaves	Used for healing, headache, hiccup, sexual weakness, fodder, furniture, agriculture tools, honey bee species.
3.	HBKU-425	*Ailanthus altissima* (Mill.) Swingle.	15	1.00	51	3.40	Whole plant	Used for dysentery, curing of fever, fodder fuel, building, furniture.
5.	HBKU-426	*Morus nigra* L.	15	1.00	47	3.13	Fruit, leaves, wood	Used for curing tonsils, cough and throat infections also used in fodder, furniture, timber wood, making baskets.
6.	HBKU-427	*Cannabis sativa* Linn**.**	15	1.00	44	2.93	Shoots	Sedative, narcotic, analgesic and used for wound healing and in hallucination.
7.	HBKU-428	*Morus alba* L.	15	1.00	42	2.80	Fruit, leaves, wood	Used for curing tonsils, cough and throat infections also in fodder, furniture, timber and making baskets.
8.	HBKU-429	*Phoenix dactylifera* Linn.	15	1.00	40	2.67	Fruit and leaves	Laxative, used in making ropes and mats. Fruits are also helpful for sexual weakness
9.	HBKU-430	*Saccharum spontaneum* L	14	0.93	40	2.67	Shoots	Used in making brooms and baskets, winnowing trays, and writing pen locally called as Qalm

10.	HBKU-431	*Dalbergia sissoo* Roxb.	15	1.00	39	2.60	Bark, leaves and wood	Used for curing abdominal pain, backache, furniture, agriculture tools. Timber, fuel and fodder
11.	HBKU-432	*Calotropis procera* (Ait.) Ait.f.	15	1.00	37	2.47	Fruit, latex, leaves	Used for curing stomachache and body pain, wound healing, fever antidote for snake and scorpion bites
12.	HBKU-433	*Melia azedarach* L.	15	1.00	37	2.47	Leaves, fruit, wood	Used for piles relief, diabetes, wound healing, physical injuries, fodder, furniture, timber, fire wood
13.	HBKU-434	*Dodonaea viscosa* (L.) Jacq.	15	1.00	32	2.13	Shoots	Anthelmintic, used in roofs, fuel and making brooms
14.	HBKU-435	*Albizia lebbeck* (L.) Benth.	15	1.00	32	2.13	Leaves, fruits and wood	Used for diabetic disorders, fodder. timber, furniture and firewood
15.	HBKU-436	*Populus euphratica* Olivier.	15	1.00	31	2.07	Wood, young shoots, leaves	Used for fodder, timber, furniture, fire wood and making baskets
16.	HBKU-437	*Ricinus communis* L.	14	0.93	31	2.07	Leaves and oil	Used for constipation, muscle relaxation and delivery cases, wound healing and for abortion purposes.
17.	HBKU-438	*Salix tetrasperma* Roxb	15	1.00	30	2.00	Wood	Used for furniture, timber, firewood, making sports items and control erosion.
18.	HBKU-439	*Euphorbia helioscopia* L.	15	1.00	29	1.93	Whole plant	Laxative, latex is poisonous. It causes irritation and swelling of skin. It may cause death of animals
19.	HBKU-440	*Cynodon dactylon* (Linn.) Pers.	15	1.00	26	1.73	Shoots	Growing in lawn and used as a fodder
20.	HBKU-441	*Desmostachya bipinnata* (Linn.) Stapf	15	1.00	25	1.67	Shoots	Used as mats in Masjids and as a fodder
21.	HBKU-442	*Eucalyptus lanceolatus* Honey	15	1.00	25	1.67	Wood	Used for furniture, timber and fuel wood

22.	HBKU-443	*Phragmites karka* (Retz.) Trin. ex steud.	14	0.93	24	1.60	Shoots	Use as thatching material in mud houses; making kites, also in paper industry and fuel
23.	HBKU-444	*Tribulus terrestris* Linn.	13	0.87	23	1.53	Shoot	Used for kidney stone and curing backache.
24.	HBKU-445	*Chenopodium album* L.	15	1.00	20	1.33	Whole plant	Used for curing animal diarrhea also in vegetable and fodder.
25.	HBKU-446	*Mentha longifolia* (L.) Huds.	15	1.00	20	1.33	Leaves	Used to cure stomachache, indigestion, carminative and as a flavoring agent
25.	HBKU-447	*Asparagus adscendens* Roxb.	14	0.93	19	1.27	Shoots	Young shoots are used as vegetable and fire wood
26.	HBKU-448	*Broussonetia papyrifera* (L.) L'Herit. ex Vent.	14	0.93	19	1.27	Leaves and wood	Used as fodder, firewood. It causes allergies.
27.	HBKU-449	*Saccharum griffithii* Munro ex Boiss.	13	0.87	19	1.27	Shoots	Used as fodder and for Roofs thatching of mud houses
28.	HBKU-450	*Cymbopogan jawarancusa* (Jones) Schult.	12	0.80	19	1.27	Shoots	Used foe fodder and laid on floors in masjids
29.	HBKU-451	*Verbascum thapsus* L.	12	0.80	18	1.20	Shoots	Analgesic,used fordiarrhea, wound healings and dysentery of cattle
30.	HBKU-452	*Oxalis corniculata* L.	15	1.00	17	1.13	Whole plant	used for stomachache and as fodder
31.	HBKU-453	*Citrus limon* (L.) Osbeck	14	0.93	17	1.13	Fruits	Regulate blood circulation, cure sexual weakness and for burning of belly fats
32.	HBKU-454	*Otostegia limbata* (Benth.) Boiss.	11	0.73	17	1.13	Flower and branches	Used to cure eye irritation, also for making fences and fuel wood
33.	HBKU-455	*Amaranthus viridus* L.	15	1.00	16	1.07	Whole plant	Used as vegetable and fodder
34.	HBKU-456	*Chenopodium ambrosioides* Linn.	14	0.93	16	1.07	Whole plant	Used as vegetable and fodder

35.	HBKU-457	*Bauhinia variegata* Linn.	12	0.80	16	1.07	Fruit, wood	Used as vegetable also in timber wood and fuel wood
36.	HBKU-458	*Nerium oleander* Linn.	12	0.80	16	1.07	Leaves	Used for curing dental problems. cultivated as ornamental. It is honey bee species
37.	HBKU-459	*Cyperus rotundus* Linn.	11	0.73	16	1.07	Whole plant	Used to cure mild fever and as fodder
38	HBKU-460	*Fumaria indica* (Hausskn.) Pugsley.	11	0.73	16	1.07	Whole plant	Used as blood purifier also for itching and diuretic
39.	HBKU-461	*Justicia adhatoda* L.	11	0.73	16	1.07	Leaves	Used to cure wounds, cough, dysentery and diarrhea
40.	HBKU-462	*Xanthium strumarium* L	15	1.00	15	1.00	Shoots	Used as fuel wood
41.	HBKU-463	*Parthenium hysterophorus* Linn.	15	1.00	15	1.00	Whole plant	Used as fuel wood
42.	HBKU-464	*Datura innoxia* Miller.	14	0.93	15	1.00	Leaves	It is poisonous. Used for poxes to remove the pus
43.	HBKU-465	*Amaranthus spinosus* Linn.	14	0.93	15	1.00	Whole plant	Young leaves are used as vegetable and fodder
44.	HBKU-466	*Mallotus philippensis* (Lam.) Müll. Arg.	13	0.87	15	1.00	Fruits	Fruits are used to extract red dye. decoction is helpful against pimples
45.	HBKU-467	*Canna indica* L.	11	0.73	15	1.00	Whole plant	Cultivated as ornamental
46.	HBKU-468	*Echinochloa colona* (L.) Link	14	0.93	14	0.93	Shoots	Fodder for cattle
47.	HBKU-469	*Olea ferruginea* Wall. ex Aitch.	14	0.93	14	0.93	Seeds	Used to relieve backache also in making various tools
48.	HBKU-470	*Sonchus asper* (L.) Hill.	13	0.87	14	0.93	Whole plant	Used as fodder which help in production of milk

49.	HBKU-471	*Tamarix aphylla* (L.) Karst.	13	0.87	14	0.93	Bark	Used to cure toothache and wound healing
50.	HBKU-472	*Adiantum caudatum* L.	9	0.60	14	0.93	Frond	Used as expectorant, emetic and diuretic
51.	HBKU-473	*Achyranthes aspera* Linn.	12	0.80	13	0.87	Whole plant	Used as blood purifier and as an antidote agent.
52.	HBKU-474	*Cuscuta reflexa* Roxb.	12	0.80	13	0.87	Whole plant	Used against teeth and gums problems. Helpful in mild fever.
53.	HBKU-475	*Dichanthium annulatum* (Forssk.) Stapf	12	0.80	12	0.80	Shoots	Uses as good source of fodder
54.	HBKU-476	*Aerva javanica* (Burm.f.) Juss. ex Schult.	12	0.80	12	0.80	Whole plant	Used as fire wood plant.
55.	HBKU-477	*Boerhavia procumbens* Banks ex Roxb	12	0.80	12	0.80	Whole plant	Used for curing lever disorders and fodder
56.	HBKU-478	*Arthraxon prionodes* (Steud.) Dandy	11	0.73	11	0.73	Whole plant	Used as fodder
57.	HBKU-479	*Capsella bursa-pastoris* (L.) Medik.	10	0.67	11	0.73	Shoots	Young leaves are used as vegetable and fodder
58.	HBKU-480	*Convolvulus arvensis Linn.*	9	0.60	11	0.73	Shoot	Used for curing skin disorder also as a fodder
59.	HBKU-481	*Heliotropium strigosum* willd.	10	0.67	10	0.67	Shoots	Used against diabetics and to regulate blood pressure
60.	HBKU-482	*Apluda mutica* L.	9	0.60	9	0.60	Whole plant	Used as fodder

Table. 2. Pearson correlation coefficient

	Correlation index	RFC	UV
	Pearson Correlation	1	.540**
RFC	Sig. (2-tailed)		.000
	N	60	60
	Pearson Correlation	.540**	1
UV	Sig. (2-tailed)	.000	
	N	60	60

**. Correlation is significant at the 0.01 level (2-tailed).

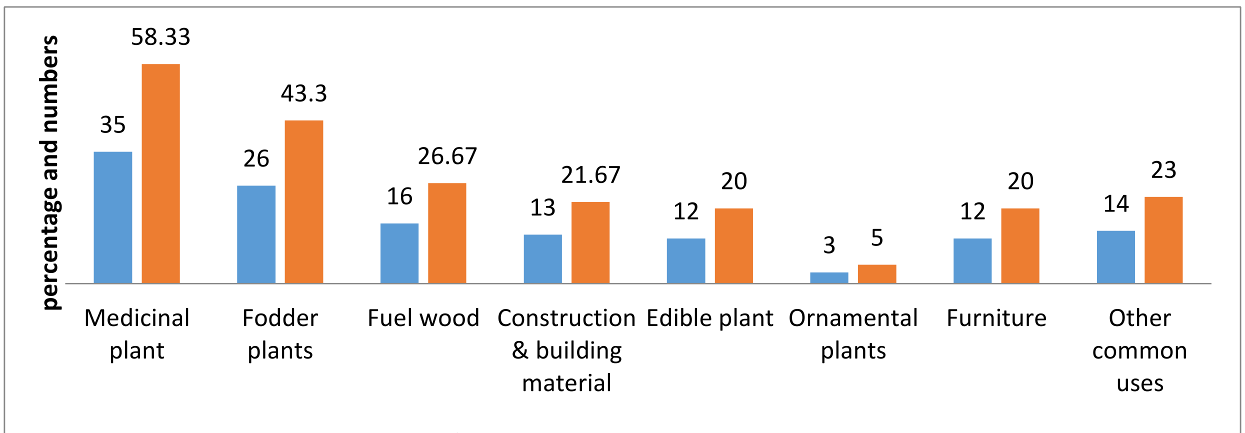

Figure 1. Ethnobotanical categories of plants of Tehsil Razar, Swabi.

Table.3. Categories of plants used ethnobotanically in Tehsil Razar, Swabi

S. No.	Category	No. of species	Percentage
1	Pteridophytes	01	1.7
2	Monocot	13	21.7
3	Dicot	46	76.7

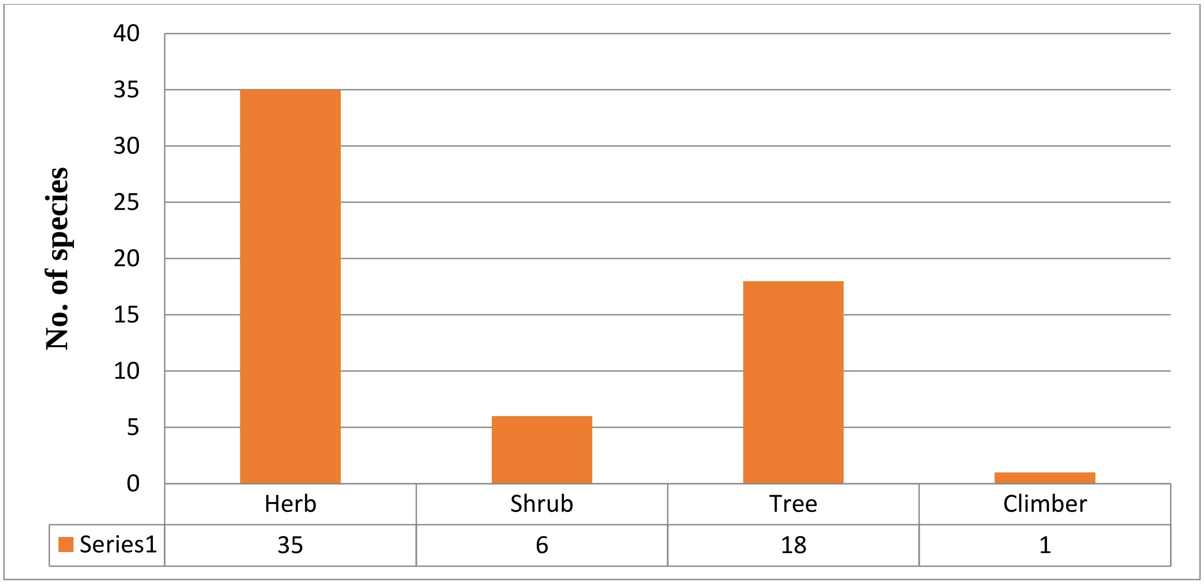

Figure 2. Herb, shrub and tree used ethnobotanically in Tehsil Razar, Swabi

Quantitative Relationships: RFC and UV

The strong correlation between RFC and UV (PCC = 0.01, $p < 0.01$) provides robust evidence of the concordance between local knowledge and species utility. This finding aligns with studies demonstrating that plants with high community knowledge often exhibit greater ethnobotanical value (Rai et al., 2022). However, the increase in UV of popular species could be a warning for overexploitation, as higher utilization pressure can lead to resource depletion (Mehmood et al., 2023). The increased use values for certain species highlight the need for sustainable harvesting practices and conservation strategies. Overexploitation of culturally and economically significant species, such as Acacia spp., could lead to their decline, affecting local ecosystems and livelihoods. Promoting awareness and integrating ethnobotanical knowledge into conservation policies are essential steps to ensure sustainable use of these resources (Ahmed et al., 2022). The high reliance on specific species for multiple purposes could lead to overexploitation, threatening their availability and ecological balance. This calls for integrated conservation strategies that involve the local community, aiming to sustainably manage these species while preserving their traditional knowledge (Mehmood et al., 2023).

Conclusion

This ethnobotanical study underscores the cultural and ecological importance of 60 plant species across 37 families, revealing their extensive use in medicine, fodder, construction, and other domains. The dominant families, including Poaceae and Amaranthaceae, contribute diverse resources, with *Acacia modesta*, *Acacia nilotica subsp. nilotica*, and *Ailanthus altissima* standing out due to their high use values and multifaceted applications. The strong correlation between Relative Frequency of Citation (RFC) and Use Value (UV) emphasizes the community's reliance on these plants, necessitating targeted conservation strategies to sustain their availability and ecological roles.

Declaration

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Authors contribution: Siraj Ud Din design the pojrct and Writing –original draft, Syed Adil Hayat and Pukraj Ud Din collect and analyzed the data, , Abdul Qadir, Mohib Shah, Tabassum Yaseen, Farrukh Hussain and Ibrahim Khan are review the data. All authors have read and agreed to the published version of the manuscript.

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