



Research Article

Intercropping of maize with soybean under integrated nutrient management showcases the role of organic fertilizers in silage production and quality

Ali Hamed^{1*}, Muhammad Shahid Ibni Zamir¹, Asif Tanveer¹, Muhammad Yaseen²

¹ Department of Agronomy, University of Agriculture, Faisalabad, Pakistan.

² Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan.

* Correspondence: ali.hamid91@gmail.com

Abstract: The world population has been on the rise, and higher food demand is need of the hour. Increase in forage production is thus required to meet the increasing demand, therefore, this study was planned for enhancing forage quality and quantity alongside synthesis of quality silage from corn stover. Hence, maize hybrids were intercropped with soybeans and given reduced and full doses of chemical fertilizers integrated with biofertilizers (plant growth-promoting rhizobacteria (PGPR) and/or organic fertilizers, compared to the recommended dose of fertilizers, and productivity of fresh fodder as well as the quality of silage were measured. It was observed that the PGPR-coated recommended dose of fertilizer (nitrogen 247 kg/ha, phosphorus 144 kg/ha, and potassium 92 kg/ha) showed maximum support to plants' growth (plant height, number of leaves, fresh forage production) and offered a better quality of silage through improvement in dry matter, crude protein, neutral detergent fiber, acid detergent fiber, hemicellulose and cellulose, and decrease in pH. Similarly, integration of reduced doses of chemical fertilizers (nitrogen 123 kg/ha, phosphorus 144 kg/ha, and potassium 92 kg/ha) with organic as well as biofertilizers also showed all morphological parameters of the forage, as well as lactic acid, dry matter, pH, hemicellulose, and neutral detergent fiber of the silage statistically at par with the recommended dose of chemical fertilizers.

Keywords: cereal, legume, maize, soybean, intercropping, plant nutrition, forage preservation

Citation: Hamed, A.; Zamir, M.S.I.; Tanveer, A.; Yaseen, M. Intercropping of maize with soybean under integrated nutrient management showcases the role of organic fertilizers in silage production and quality. *Pakistan Journal of Biochemistry and Biotechnology*, 2022, Volume 3 (1); 119-135.

<https://doi.org/10.52700/pjbb.v3i1.100>

Received: 26 Jan 2022

Accepted: 17 Feb, 2022.

Published: 30 June, 2022

1. Introduction

Food demand has been rising owing to the continuous rise in global population which is predicted to be 8.6 billion in 2030 and 9.8 billion in 2050 [1], hence ensuring food security for every individual under the changing climate scenarios is one of the most pressing challenges. Such challenges can be met through sustainable food production without compromising the resources including those of soil and environment [2]. Among related issues, extensive use of chemical fertilizers is of rising concern due to lateral effects on soil and other ecosystems, therefore, we must look for sustaining the production of crops as well as livestock with alternative resources. The livestock sector particularly faces issues of

low crop nutrition, thus biological options like those of organic fertilizers, biofertilizers, and incorporation of leguminous crops should be considered.

Livestock contributes significantly towards food requirements but remains a neglected sector in many of the developing countries where subsistence farming is practiced. In contrast, the livestock population is observing an increase of approximately 1.5% globally [3] and 4.2% in Pakistan [4]; therefore, feed requirement also increases to fulfill the animals' dietary needs. However, the lower yield of fodder and its unavailability during critical periods is causing a decrease in livestock productivity, particularly in Pakistan. With every passing decade, almost 2% area under fodder cultivation is lost. Alongside, the farmers have to face two fodder scarcity periods (November to January) and (May-June), due to which this situation is further worsened (Agricultural Statistics of Pakistan 2018-19). Thereby, a decrease in area and competition with significant crops (e.g., wheat) cause an inadequate supply of quality fodder for livestock productivity. On the contrary, a bulk amount of fodder is available in the peak fodder producing seasons, but that is not being stored for a more extended period due to a lack of processing techniques and storage capacity. The processed feed is therefore needed instead of fresh fodder. Using processed feed has certain benefits as it overcomes the seasonal fodder deficiency and has higher nutritional value.

When it is being produced in larger quantities, the conservation of forage can ensure the availability of feed to animals when there is minimal or lower forage production. This will allow farmers to prevent wastage of fresh forage due to the maturation of forage. Ultimately the conservation of forage as fodder will ensure the availability of nutritious feed to the livestock throughout the year in sufficient quantities, thus preventing the decrease in their productivity [5]. Silage is a viable alternative animal fodder having the advantage of good palatability, high digestibility, and quality [6]. Estimated, 0.05 million hectares of maize grown in Pakistan is used for silage production [7]. Whole plant corn silage contributes to being a significant forage and energy source of livestock production. It would also help in enhancing the nutritional status of forage besides reducing the costs. The ensiling process also guarantees long-term use of silage for the animals, or in case of excess, its service for biogas in digesters [8]. The case of Pakistan especially asks for silage production, which will better secure the farming community than that of dependency on fresh fodder.

However, maize production is heavily dependent on synthetic fertilizers application [9]. Maize shows fast growth due to which it needs a continuous supply of essential nutrients, mainly those of nitrogen, phosphorus, and potassium, which are generally supplied through synthetic fertilizers, thus putting enormous pressure on farmers financially and on the environment in terms of pollution [10]. The use of chemical fertilizers is considered an efficient way to recover the gap of soil nutrients and improve crop production. However, the use of synthetic fertilizers in underdeveloped communities is insignificant as most of the resource-poor smallholder farmers face difficulties in affording them [11]. Similarly, extended use of chemical fertilizers in intensive cropping systems leads to compromise of beneficial microbes' functionality [12] which leads to abruptions in nutrient availability consequently leading to poor soil health and crop production [11]. These effects can be alleviated with bulk-available organic sources of plant nutrition, which can improve soil characteristics important for crop production. Organic sources of fertilizers like farmyard manure (FYM), chicken manure, sheep manure, and incorporation of crop residues have been used for crop production in addition to chemical fertilizers [13].

Similarly, biofertilizers have shown potential in enhancing crop growth and production [14]. Numerous studies have reported encouraging effects of organic source fertilizers on the soil [15, 16]. However, organic source fertilizers alone for sustainable crop production are insufficient because of the lower quantity of nutrients as well as the slow release of nutrients [17]. Incorporation of organic sources at a higher amount is beneficial but may not be affordable by smallholder farmers.

Therefore, neither the sole application of chemical fertilizer nor organic fertilizer or biofertilizers can help achieve sustainable crop productivity under an intensive farming system. To achieve better soil health and improved productivity of crops, the shared use of organic, inorganic fertilizers, and biofertilizers together with other nutrient management practices like intercropping with legumes are very important. Soybean a legume can fix nitrogen from the atmosphere for its use as well as other intercropped crops symbiotically, and it does reduce the need for a nitrogenous source of

fertilizer [18]. Soybean is quite a new crop in Pakistan and its intercropping with maize [19, 20], sorghum [21, 22], and cotton [23] has already been investigated. Reduced fertilizer requirement, amelioration of weeds, and better crop production are the benefits observed, therefore, intercropping of soybean with maize hybrids to improve forage and silage production alongside grain purposes is being explored in this study. As the system of intercropping utilizes the resources efficiently due to which crop production is enhanced while, on the other hand, sole cropping does not exploit the available resources effectively [24].

The use of organic fertilizers and biological nitrogen fixation may be adopted together to meet the nutrient requirements. Nitrogen can be applied directly to crops through inoculation of microbes or by intercropping some leguminous crops with cereals to fulfill the nitrogen requirement, thus minimizing production cost [25]. The bio-fertilizers can enhance the accessibility of phosphorus present in the soil, produce phytohormones, help the plants with 1-aminocyclopropane-1-carboxylate (ACC) deaminase activity, and iron chelation [26, 27]. The organic sources of nutrient supply like FYM, poultry manure (PM), and bio-fertilizers can replace synthetic fertilizers for better harvest [28]. These sources enhance soil fertility without harming soil health and are economically cheaper than synthetic fertilizers [29].

Consequently, the combined usage of plant nutrition options like those of biological, organic as well as synthetic sources is a better option to enhance crop productivity on a sustainable basis (Mahajan et al., 2008). Some studies have already been conducted to evaluate the corn silage quality by applying different nutrients [30-32]. For instance, Erdal, Pamukcu [33] postulated that a ratio of three maize rows to one row of soybean led to improvements in different chemical characteristics of the silage. Similarly, the integration of organic and inorganic has been found to improve the silage quantity [34]. However, gaps remain in our understanding of an accumulative effect of utilizing different nutrition sources with intercropping, particularly in Pakistan. Similarly, maize hybrids are widely grown in the area; however, their growth in intercropping as well as utilization as silage remains widely unexplored; therefore, it was hypothesized that reduced dosage of fertilizers used in integration with biological and organic sources may result in better crop production with reduced input costs i.e., resulting from the reduced cost of fertilizers. Keeping in view the available information, this study was planned aimed at comprehending the best formulation of nutrient sources as well intercropping to be used in fodder and silage production.

2. Materials and Methods

A two-year field experimental setup was conducted at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan (31°26'34.8 "N 73°04'25.1 "E) during summer 'locally known as Kharif' season of 2018 and 2019. Data on weather conditions during the experimental period are given in supplementary information (Table S1). The soil texture was sandy loam, and the pH and electrical conductivity (EC) were 7.8, and 0.1, respectively.

This study was conducted in a randomized complete block design (RCBD), and each experimental unit's dimensions were 7 m × 4.8 m. Treatments as given in Table 1 (replicated thrice) included T1: recommended dose (The recommendations are made by local agriculture extension authorities. As biological nitrogen fixation is there for soybean, therefore, reduced dosage; half the recommended dose was considered to test the requirement of nitrogen) of nitrogen, phosphorus, and potassium (247:144:92), T2: recommended dose of NPK coated with plant growth-promoting rhizobacteria (PGPR), T3: A half dose of NPK (123:72:46) coated with PGPR, T4: the half dose of NPK + poultry manure (PM) at the rate of 4 t ha⁻¹, T5: the half dose of NPK + farmyard manure (FYM) at the rate of 6 t ha⁻¹, T6: The half dose of NPK + bio-fertilizer at the rate of 25 kg ha⁻¹, T7: Bio-fertilizer (25 kg ha⁻¹) + FYM (6 t ha⁻¹), and T8: bio-fertilizer (25 kg ha⁻¹) + PM (4 t ha⁻¹). For the T2 and T3, the formulation was calculated and applied from commercially available Plant Growth Promoting Bacteria (PGPB)-fortified Nutraful DAP and Nutraful Urea (Jaffer Agro Services, Karachi, Pakistan). For other chemical fertilizer treatments, normal formulations of available DAP and Urea were used (Sona Urea and FFC DAP, Fauji Fertilizer Company Limited, Rawalpindi, Pakistan). Poultry manure (dry matter: 41%, moisture: 47%, nitrogen 0.87%, phosphorus 0.64%, potassium 0.26%) and farmyard manure (dry matter: 18%, moisture: 61%, nitrogen 0.43%, phosphorus 0.16%, potassium 0.51%) were collected from nearby

farms. Bio-fertilizer was obtained from Ayub Agriculture Research Institute, Faisalabad, Pakistan, under the brand name Jaraseemi Teeka which included *Azotobacter* sp., *Azospirillum* sp. and *Pseudomonas* sp. For maize and *Rhizobium japonicum* for soybean.

Table 1 Treatments applied in this study

| Treatments | Explanation |
|------------|--|
| T1 | Recommended dose of nitrogen (247 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from DAP and Urea |
| T2 | The recommended dose of NPK from plant growth-promoting rhizobacteria (PGPR)-coated-Nutraful DAP and -Nutraful Urea |
| T3 | Half dose of (123 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from plant growth-promoting rhizobacteria (PGPR) coated-Nutraful DAP and -Nutraful Urea |
| T4 | Half dose of NPK + poultry manure (PM) at the rate of 4 t ha ⁻¹ |
| T5 | Half dose of NPK + farmyard manure (FYM) at the rate of 6 t ha ⁻¹ |
| T6 | Half dose of NPK + bio-fertilizer at the rate of 25 kg ha ⁻¹ |
| T7 | Bio-fertilizer (25 kg ha ⁻¹) + FYM (6 t ha ⁻¹) |
| T8 | Bio-fertilizer (25 kg ha ⁻¹) + PM (4 t ha ⁻¹) |

The intercropping was uniform in all the treatments, and seeds of maize (cultivar DK-6789) and soybean (cultivar Faisal) were collected from Bayer Crop Science Pakistan Pvt. Ltd. and Ayub Agricultural Research Institute, Faisalabad, respectively. The seeds were treated with 9 g Argyl Super 62.5% WS per kilogram seed to avoid seed-borne diseases. Maize and soybean were sown on ridges (75 cm apart) through the dibbling method at the seed rate of 25 kg ha⁻¹ for maize and 30 kg ha⁻¹ for soybean. Each plot had six rows (30 plants of maize per row, and 40 plants of soybean per row), three for maize and three for soybean, and plant to plant distance for maize was 20 cm, while for soybean it was 15 cm. Manual weeding was performed 20 days after sowing, and the field was irrigated every seven days until the grain formation stage (10-11 irrigation frequencies making the delta of water 30-35 acre inches). Treatments: farmyard and poultry manures were added before seedbed preparation. In contrast, chemical fertilizer was added in two doses (during the preparation of seedbed while remaining nitrogen was given with each irrigation) while biofertilizers were added with the seed. Biofertilizer application was performed according to Rehman, Farooq [35]. Sowing was carried out on August 28, 2018, and August 23, 2019, while harvests were made on November 14, 2018, and November 12, 2019.

For ensiling, fodder was harvested and chopped into 3-4 cm long discs using a chaff cutter. The fodder was then transferred to plastic jars, pressed hard to remove air, sealed, and kept airtight for 40 days. Samples were taken after the ensiling period and subjected to parameters as explained below.

2.1. Quantification of growth and quality parameters:

At harvest, plant height (cm), number of leaves per plant, dry weight per plant (g), fresh forage yield at harvest (t ha⁻¹), and dry matter yield at harvest (t ha⁻¹) were recorded. Among the quality parameters, crude protein, fiber, and total ash percentage were recorded. Crude protein was determined by the macro-Kjeldahl method [36], while crude fiber was determined by the Soxhlet apparatus method [37]. The total ash percentage was calculated by AOAC's official method 942.05 [38].

For determination of silage quality; lactic acid [39], pH (1:10 in distilled water), dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose, and cellulose were recorded following the methods given by [40, 41].

2.2. Statistical analysis

The data obtained on all observations were analyzed statistically by employing the Fischer analysis of variance technique through Statistix-8.1 (Analytical Software, FL, USA) [42]. Comparison of treatments was done at a 5% probability level of Tukey's HSD test.

3. Results

3.1. Agronomic parameters

3.1.1. Plant height of maize and soybean at harvesting (cm)

Plant height of maize and soybean was significantly impacted by the application of different treatments in both years (maize 2018 ($p < 0.001$) and 2019 ($p < 0.001$; soybean 2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 2). For maize, plant height ranged from 151.2 cm to 189.7 cm in the first year of the experiment and 167.77 cm to 192 cm in the second year. In both years, maximum plant height was obtained where PGPR-coated recommended dose of NPK was added and was followed by that of the recommended dose of NPK application (Tukey's HSD test). While minimum plant height was observed in treatment, which received PGPR-coated half dose of NPK in both years.

For soybean, maximum plant height was observed in T2 (PGPR-coated recommended dose of NPK) followed by T1 (Recommended dose of NPK) during both years of study. While minimum plant height was observed in T3 (PGPR-coated half dose of NPK), which was statistically at par with T8 (Biofertilizer integrated with PM) in 2018, but in 2019 it was followed by T8 (Biofertilizer combined with PM) (Table 2).

It is notable that half the dose of chemical fertilizer when used with the farmyard manure and the biofertilizers, but not with the poultry manure, showed the same results as the recommended dose of chemical fertilizer. It is further evident from the sole application of half dose of chemical fertilizer (Table 2). On the other hand, the application of only biofertilizers and organic fertilizers as seen in T7 and T8 yielded the lowest plant height.

3.1.2. Number of leaves per plant of maize and soybean at harvesting

The number of leaves of maize and soybean was significantly affected by the application of different treatments in both years (maize 2018 ($p < 0.001$) and 2019 ($p < 0.001$; soybean 2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 2). The highest number of leaves in maize was observed in T2 (PGPR-coated recommended dose of NPK), and it was followed by T1 (Recommended dose of NPK) during both study years. While least number of leaves was observed in T3 (PGPR-coated half dose of NPK), which was statistically at par with T8 (Biofertilizer integrated with PM) in 2018, but in 2019 it was followed by T8 (biofertilizer integrated with PM) and T7 (biofertilizer integrated with FYM).

For soybean, the maximum number of leaves was observed in T2 (PGPR-coated recommended dose of NPK), and it was followed by T1 (Recommended dose of NPK) during both study years. While the minimum number of leaves was observed in T3 (PGPR-coated half dose of NPK), which was followed by T8 (Biofertilizer integrated with PM) during both study years (Table 2). The case of the number of leaves also showed that integration of organic or biofertilizers helped in increase in their number, and even the poultry manure contributed at a similar level as those of biofertilizers and farmyard manure which was not the case in plant height.

3.1.3. Dry weight per plant of maize and soybean at harvesting (g)

Dry weight per plant of maize and soybean was significantly affected by the application of different treatments in both years (maize 2018 ($p < 0.001$) and 2019 ($p < 0.001$; soybean 2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 2). Maximum dry weight in maize was observed in T2 (PGPR-coated recommended dose of NPK) and was followed by T1 (Recommended dose of NPK) during both years of study. While minimum dry weight was observed in T3 (PGPR-coated half dose of NPK) and it was followed by T8 (Biofertilizer integrated with PM) in 2018 in both years.

For soybean, maximum dry weight was observed in T2 (PGPR-coated recommended dose of NPK), and it was followed by T1 (Recommended dose of NPK) during both years of study. While minimum dry weight was observed in T3 (PGPR-coated half dose of NPK) and was followed by T8 (Biofertilizer integrated with PM) during both study years (Table 2).

Dry weight per plant was the same for the normal as well as PGPR-coated fertilizers (T1 and T2). Similarly, the contribution from the organic and biofertilizers alone or in integration with the chemical fertilizers was also not equal to the chemical fertilizers.

Table 2 Effect of different treatments on plant height at harvesting (cm), number of leaves per plant and dry weight per plant at harvesting (g)

| Treatments | Plant height at harvesting (cm) | | | | Number of leaves per plant | | | | Dry weight per plant at harvesting (g) | | | |
|----------------|---------------------------------|----------|----------|----------|----------------------------|----------|---------|---------|--|----------|---------|---------|
| | Maize | | Soybean | | Maize | | Soybean | | Maize | | Soybean | |
| | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| T ₁ | 183.3 ab | 188.7 ab | 118.8 ab | 123.0 ab | 15 ab | 16.7 ab | 85.7 b | 91.3 ab | 140.2 a | 142.2 a | 32.1 a | 34.2 a |
| T ₂ | 189.7 a | 192.0 a | 124.4 a | 126.0 a | 16.3 a | 17.7 a | 93.7 a | 92.7 a | 144.3 a | 147.0 a | 34.1 a | 35.8 a |
| T ₃ | 151.2 e | 167.8 g | 87.9 g | 98.7 g | 10 f | 13.0 e | 51.7 g | 57.0 f | 124.35 cd | 109.6 e | 19.4 e | 20.5 e |
| T ₄ | 171.7 cd | 179.3 de | 102.4 de | 112.6 d | 12.7 cd | 15.3 bcd | 71.3 d | 75.3 d | 121.07 cd | 123.8 c | 26.3 bc | 27.4 c |
| T ₅ | 180.3 abc | 186.6 bc | 113.8 bc | 120.9 b | 14.7 b | 16.3 abc | 80.3 bc | 85.7 bc | 132.9 b | 134.5 b | 28.8 b | 30.0 b |
| T ₆ | 172.5 bc | 182.3 cd | 108.4 cd | 117.0 c | 14 bc | 16.0 bcd | 74.7 cd | 81.3 cd | 128.2 bc | 129.4 bc | 28.5 b | 28.3 bc |
| T ₇ | 160.6 de | 176.1 ef | 97.2 ef | 107.8 e | 11.7 de | 15.0 cd | 65.3 e | 67.3 e | 118.07 de | 117.3 d | 23.8 cd | 24.6 d |
| T ₈ | 158.5 e | 171.7 fg | 91.3 fg | 102.7 f | 11 ef | 14.7 d | 58 f | 61.3 ef | 111 e | 112.5 de | 21.4 de | 22.3 e |
| HSD (p<0.05) | 11.1 | 4.5 | 6.6 | 3.8 | 1.6 | 1.6 | 5.9 | 6.6 | 7.2 | 6.3 | 3.0 | 2.2 |

Treatments with the same letter are statistically similar based on Tukey's HSD at 5 % level of significance. T₁: Recommended dose of nitrogen (247 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from DAP and Urea, T₂: recommended dose of NPK from plant growth-promoting rhizobacteria (PGPR)-coated-Nutraful DAP and -Nutraful Urea, T₃: half dose of (123 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from plant growth-promoting rhizobacteria (PGPR) coated-Nutraful DAP and -Nutraful Urea, T₄: half dose of NPK + poultry manure (PM) at the rate of 4 t ha⁻¹, T₅: half dose of NPK + farmyard manure (FYM) at the rate of 6 t ha⁻¹, T₆: half dose of NPK + bio-fertilizer at the rate of 25 kg ha⁻¹, T₇: bio-fertilizer (25 kg ha⁻¹) + FYM (6 t ha⁻¹), T₈: bio-fertilizer (25 kg ha⁻¹) + PM (4 t ha⁻¹)

3.1.4. Fresh forage yield at harvesting (t ha⁻¹)

Fresh forage yield of maize and soybean mixed at harvest was significantly affected by the application of different treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 3). The maximum fresh forage yield was observed in T2 (PGPR-coated recommended dose of NPK), which was statistically at par with T1 (Recommended dose of NPK) during both years of study. While minimum fresh forage yield was observed in T3 (PGPR-coated half dose of NPK), it was followed by T8 (Biofertilizer integrated with PM) in both years, but in 2019 it was statistically at par with T8 (Biofertilizer integrated with PM Table 3). The fresh forage production cleared the picture, and significant enhancement was achieved where integration of farmyard manure and biofertilizers with a half dose of chemical fertilizer were given. Although other integrated applications also showed increased fresh forage yield, yet poultry manure was not found to be as effective as the other two treatments. The lowest contribution from T7 and T8 showed that chemical fertilizers have a significant contribution towards morphological parameters of plants.

3.1.5. Dry matter yield at harvesting (t ha⁻¹)

Dry matter yield of maize and soybean mixed at harvest was significantly affected by the application of different treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 3). The maximum dry matter yield was observed in T2 (PGPR-coated recommended dose of NPK), and it was followed by T1 (Recommended dose of NPK) during both years of study. While minimum dry matter yield was observed in T3 (PGPR-coated half dose of NPK), which was followed by T8 (Biofertilizer integrated with PM) during both study years (Table 3). Dry matter yield on the contrary to fresh forage cleared the case and three treatments; recommended doses of normal and PGPR-coated chemical fertilizers, and farmyard manure integrated with a half dose of chemical fertilizer showed maximum dry matter.

3.2. Quality parameters

3.2.1. Crude protein (%)

Crude protein of maize and soybean mixed at harvest was significantly affected by the application of different treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 3). The maximum crude protein was observed in T2 (PGPR-coated recommended dose of NPK), and it was followed by T1 (Recommended dose of NPK) during both years of study. While minimum crude protein was observed in T3 (PGPR-coated half dose of NPK), which was statistically at par with T8 (Biofertilizer integrated with PM) during both study years (Table 3). In the crude protein, although the trend was similar with other parameters, yet it was important to observe that both biofertilizers and farmyard manure application (with the half dose of chemical fertilizer) showed statistically similar results.

3.2.2. Crude fiber (%)

The crude fiber of maize and soybean mixed at harvest was significantly affected by the application of different treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 3). The maximum crude fiber was observed in T2 (PGPR-coated recommended dose of NPK), and it was followed by T1 (Recommended dose of NPK) during both years of study. While, minimum CF was observed in T3 (PGPR-coated half dose of NPK), which was statistically at par with T8 (Biofertilizer integrated with PM) in 2018, but in 2019 it was followed by T8 (Biofertilizer integrated with PM, Table 3).

3.2.3. Total ash (%)

Total ash of maize and soybean mixed at harvest was significantly affected by the application of different treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 3). The maximum ash was observed in T2 (PGPR-coated recommended dose of NPK), where it was followed by T1 (Recommended dose of NPK) during both years of study. Whereas minimum ash content was observed in T3 (PGPR-coated half dose of NPK), which was statistically at par with T8 (Biofertilizer integrated with PM) in 2018, but in 2019 it was followed by T8 (Biofertilizer integrated with PM (Table 3)).

1 **Table 3** Effect of different treatments on fresh forage yield at harvesting, dry matter yield at harvesting, crude protein, crude fiber and total ash

| Treatments | Fresh forage yield at harvesting (t ha ⁻¹) | | Dry matter yield at harvesting (t ha ⁻¹) | | Crude protein (%) | | Crude fiber (%) | | Total ash (%) | |
|----------------|--|---------|--|---------|-------------------|---------|-----------------|---------|---------------|--------|
| | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| T ₁ | 60.1 ab | 61.4 ab | 21.9 ab | 21.7 ab | 14.6 ab | 15.5 ab | 27 ab | 27.5 ab | 11.4 ab | 11.7 b |
| T ₂ | 61.4 a | 62.3 a | 22.9 a | 23.0 a | 16.5 a | 17.1 a | 27.7 a | 28.7 a | 12.2 a | 12.6 a |
| T ₃ | 50.5 e | 52.4 g | 14.4 f | 14.9 e | 9.7 e | 9.5 f | 21.2 f | 20.7 g | 7.6 f | 7.7 f |
| T ₄ | 56.5 c | 57.8 de | 18.5 d | 19.3 c | 11.9 cd | 12.3 de | 23.6 d | 24.3 de | 9.8 de | 9.8 cd |
| T ₅ | 59.2 ab | 60.0 bc | 21.1 bc | 20.9 bc | 13.7 bc | 14.1 bc | 26.1 bc | 26.2 bc | 10.7 bc | 10.7 c |
| T ₆ | 58.5 bc | 58.8 cd | 20.2 c | 20.3 bc | 13 bc | 13.2 cd | 25.2 c | 25.3 cd | 10.3 cd | 10.3 c |
| T ₇ | 54.1 d | 56.1 e | 16.9 de | 17.1 d | 11.1 de | 11.3 ef | 22.7 de | 23.4 ef | 9.0 e | 9.3 de |
| T ₈ | 52 de | 54.4 f | 15.3 ef | 15.8 de | 10.2 de | 10.5 ef | 21.8 ef | 22.1 fg | 8.1 f | 8.5 ef |
| HSD (p<0.05) | 2.3 | 1.7 | 1.6 | 1.7 | 1.9 | 1.8 | 1.2 | 1.4 | 0.8 | 0.9 |

2 Treatments with the same letter are statistically similar based on Tukey's HSD at 5 % level of significance. T1: Recommended dose of nitrogen (247 kg/ha), phosphorus (144 kg/ha),
3 and potassium (92 kg/ha) from DAP and Urea, T2: recommended dose of NPK from plant growth-promoting rhizobacteria (PGPR)-coated-Nutraful DAP and -Nutraful Urea, T3: half
4 dose of (123 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from plant growth-promoting rhizobacteria (PGPR) coated-Nutraful DAP and -Nutraful Urea, T4: half dose of
5 NPK + poultry manure (PM) at the rate of 4 t ha⁻¹, T5: half dose of NPK + farmyard manure (FYM) at the rate of 6 t ha⁻¹, T6: half dose of NPK + bio-fertilizer at the rate of 25 kg
6 ha⁻¹, T7: bio-fertilizer (25 kg ha⁻¹) + FYM (6 t ha⁻¹), T8: bio-fertilizer (25 kg ha⁻¹) + PM (4 t ha⁻¹)

7

8

9 3.3. Silage characteristics

10 3.3.1. Lactic acid

11 The lactic acid of silage of maize and soybean mixture was significantly affected by the application of
12 different treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 4). The maximum LA was
13 observed in T2 (PGPR-coated recommended dose of NPK), and it was followed by T1 (Recommended
14 dose of NPK) during both years of study. While minimum LA was observed in T3 (PGPR-coated half
15 dose of NPK), which was followed by T8 (Biofertilizer integrated with PM during both study years
16 (Table 4)).

17 3.3.2. pH

18 The pH of silage of maize and soybean mixture was significantly affected by the application of different
19 treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 4). The maximum pH was observed
20 in T3 (PGPR-coated half dose of NPK) and was followed by T8 (Biofertilizer integrated with PM) during
21 both study years. While minimum pH was observed in T2 (PGPR-coated recommended dose of NPK),
22 it was followed by T1 (Recommended dose of NPK) during both years of study) (Table 4)).

23 3.3.3. Dry matter

24 Dry matter of silage of maize and soybean mixture was significantly affected by the application of
25 different treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 4). The maximum dry
26 matter was observed in T2 (PGPR-coated recommended dose of NPK), which was followed by T1
27 (Recommended dose of NPK) during both years of study. While the minimum dry matter was observed
28 in T3 (PGPR-coated half dose of NPK) and was followed by T8 (Biofertilizer integrated with PM during
29 both study years (Table 4)).

30 3.3.4. Crude protein

31 Crude protein of silage of maize and soybean mixture was significantly affected by the application of
32 different treatments in both years (2018 ($p < 0.001$) and 2019 ($p < 0.001$)) (Table 4). The maximum crude
33 protein was observed in T2 (PGPR-coated recommended dose of NPK), which was followed by T1
34 (Recommended dose of NPK) during both years of study. While the minimum dry matter was observed
35 in T3 (PGPR-coated half dose of NPK) and it was followed by T8 (Biofertilizer integrated with PM) in
36 2018. Still, in 2019 it was statistically at par with the T8 (Biofertilizer integrated with PM Table 4)).

Table 4 Effect of different treatments on lactic acid, pH, dry matter, crude protein of the silage

| Treatments | Lactic acid (%) | | pH | | Dry matter (%) | | Crude protein (%) | |
|----------------|-----------------|---------|---------|---------|----------------|----------|-------------------|---------|
| | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| T ₁ | 4.99 ab | 5.03 ab | 3.82 e | 3.81 e | 44.5 ab | 45.0 ab | 13.0 b | 13.2 ab |
| T ₂ | 5.08 a | 5.13 a | 3.79 f | 3.75 f | 45.8 a | 46.2 a | 13.7 a | 13.7 a |
| T ₃ | 4.49 f | 4.45 f | 4.02 a | 4.05 a | 36.0 f | 35.9 e | 10.1 f | 10.1 e |
| T ₄ | 4.81 d | 4.83 cd | 3.94 bc | 3.92 c | 40.7 de | 42.8 c | 11.7 d | 11.4 d |
| T ₅ | 4.96 bc | 4.99 b | 3.86 d | 3.85 d | 43.2 bc | 44.3 abc | 12.6 bc | 12.7 b |
| T ₆ | 4.90 c | 4.92 bc | 3.91 c | 3.90 c | 42.1 cd | 43.2 bc | 12.1 cd | 12.1 c |
| T ₇ | 4.66 e | 4.73 de | 3.96 b | 3.98 b | 39.4 e | 42.6 c | 11.1 e | 11.0 d |
| T ₈ | 4.60 e | 4.65 e | 4.00 a | 4.01 ab | 37.7 f | 40.0 d | 10.6 ef | 10.3 e |
| HSD (p<0.05) | 0.1 | 0.1 | 0.03 | 0.04 | 1.7 | 2.1 | 0.6 | 0.6 |

Treatments with the same letter are statistically similar based on Tukey's HSD at 5 % level of significance. T₁: Recommended dose of nitrogen (247 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from DAP and Urea, T₂: recommended dose of NPK from plant growth-promoting rhizobacteria (PGPR)-coated-Nutraful DAP and -Nutraful Urea, T₃: half dose of (123 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from plant growth-promoting rhizobacteria (PGPR) coated-Nutraful DAP and -Nutraful Urea, T₄: half dose of NPK + poultry manure (PM) at the rate of 4 t ha⁻¹, T₅: half dose of NPK + farmyard manure (FYM) at the rate of 6 t ha⁻¹, T₆: half dose of NPK + bio-fertilizer at the rate of 25 kg ha⁻¹, T₇: bio-fertilizer (25 kg ha⁻¹) + FYM (6 t ha⁻¹), T₈: bio-fertilizer (25 kg ha⁻¹) + PM (4 t ha⁻¹)

55

56 3.3.5. Neutral detergent fiber (NDF)

57 The neutral detergent fiber of silage of maize and soybean mixture was significantly affected by the
58 application of different treatments in both years (2018 ($p<0.001$) and 2019 ($p<0.001$)) (Table 5). The
59 maximum NDF was observed in T2 (PGPR-coated recommended dose of NPK), and it was followed
60 by T1 (Recommended dose of NPK) during both years of study. Minimum NDF was observed in T3
61 (PGPR-coated half dose of NPK), which was statistically at par with T8 (Biofertilizer integrated with
62 PM) in 2018, but in 2019, it was followed by T8 (Biofertilizer integrated with PM, (Table 5)).

63 3.3.6. Acid detergent fiber (ADF)

64 The acid detergent fiber of silage of maize and soybean mixture was significantly affected by the
65 application of different treatments in both years (2018 ($p<0.001$) and 2019 ($p<0.001$)) (Table 5). The
66 maximum ADF was observed in T2 (PGPR-coated recommended dose of NPK), which was followed
67 by T1 (Recommended dose of NPK) during both years of study. While minimum ADF was observed
68 in T3 (PGPR-coated half dose of NPK) and it was followed by T8 (Biofertilizer integrated with PM)
69 during both years of study (Table 5)).

70 3.3.7. Hemicellulose

71 Hemicellulose of silage of maize and soybean mixture was significantly affected by the application of
72 different treatments in both years (2018 ($p<0.05$) and 2019 ($p<0.001$)) (Table 5). The maximum
73 hemicellulose was observed in T2 (PGPR-coated recommended dose of NPK), which was followed by
74 T1 (Recommended dose of NPK) during both years of study. While minimum hemicellulose was
75 observed in T3 (PGPR-coated half dose of NPK) and was statistically at par with T8 (Biofertilizer
76 integrated with PM) during both years of study (Table 5)).

77 3.3.8. Cellulose

78 The cellulose of silage of maize and soybean mixture was significantly affected by the application of
79 different treatments in both years (2018 ($p<0.001$) and 2019 ($p<0.001$)) (Table 5). The maximum cellulose
80 was observed in T2 (PGPR-coated recommended dose of NPK) and was followed by T1 (Recommended
81 dose of NPK) during both years of study. While minimum cellulose was observed in T3 (PGPR-coated
82 half dose of NPK), which was followed by T8 (Biofertilizer integrated with PM) during both years of
83 study (Table 5)).

Table 5 Effect of different treatments on neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose and cellulose of the silage

| Treatments | Neutral detergent fiber (NDF) % | | Acid detergent fiber (ADF) % | | Hemicellulose (%) | | Cellulose (%) | |
|----------------|------------------------------------|---------|---------------------------------|--------|-------------------|----------|---------------|---------|
| | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| T ₁ | 51.2 ab | 51.5 b | 42.9 ab | 43.2 b | 8.3 a | 8.2 ab | 35.8 a | 36.3 b |
| T ₂ | 51.9 a | 52.8 a | 43.7 a | 44.1 a | 8.3 a | 8.7 a | 36.8 a | 37.7 a |
| T ₃ | 45.6 f | 46.1 e | 38.2 g | 38.3 h | 8.2 ab | 7.8 abcd | 28.2 e | 29.2 f |
| T ₄ | 48.4 d | 48.5 c | 40.9 de | 41.0 e | 7.8 ab | 7.4 bcd | 31.8 c | 32.6 d |
| T ₅ | 50.7 b | 50.6 b | 42.3 bc | 42.6 c | 7.5 ab | 8.0 abc | 34.6 b | 35.0 c |
| T ₆ | 49.4 c | 49.1 c | 41.6 cd | 41.9 d | 7.5 ab | 7.3 cd | 33.6 b | 33.9 c |
| T ₇ | 47.5 e | 47.1 d | 40.3 e | 40.1 f | 7.4 ab | 7.0 d | 30.6 d | 31.4 de |
| T ₈ | 46.7 e | 46.7 de | 39.2 f | 39.4 g | 7.2 b | 7.3 bcd | 29.9 d | 30.4 ef |
| HSD (p<0.05) | 0.9 | 0.9 | 0.8 | 0.6 | 0.9 | 1.0 | 1.1 | 1.2 |

Treatments with the same letter are statistically similar based on Tukey's HSD at 5 % level of significance. T₁: Recommended dose of nitrogen (247 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from DAP and Urea, T₂: recommended dose of NPK from plant growth-promoting rhizobacteria (PGPR)-coated-Nutraful DAP and -Nutraful Urea, T₃: half dose of (123 kg/ha), phosphorus (144 kg/ha), and potassium (92 kg/ha) from plant growth-promoting rhizobacteria (PGPR) coated-Nutraful DAP and -Nutraful Urea, T₄: half dose of NPK + poultry manure (PM) at the rate of 4 t ha⁻¹, T₅: half dose of NPK + farmyard manure (FYM) at the rate of 6 t ha⁻¹, T₆: half dose of NPK + bio-fertilizer at the rate of 25 kg ha⁻¹, T₇: bio-fertilizer (25 kg ha⁻¹) + FYM (6 t ha⁻¹), T₈: bio-fertilizer (25 kg ha⁻¹) + PM (4 t ha⁻¹)

4. Discussion

Maize and soybean showed significant differences in agronomic, quality parameters, and silage characteristics (Tables 2-5) where PGPR-coated NPK, when applied at the recommended dose showed maximum growth and productivity. Similarly, integrated use of either chemical fertilizers with organic fertilizers or biofertilizers with the latter also showed promising results, which may reduce our reliance on synthetic fertilizers. A combination of NPK with FYM, for example, was the economically (considering the very low cost of FYM, and the usual practice of unpaid receiving of FYM from other farmers) best treatment which gave statistically same results with recommended doses at few instances, as it cost only half the price of fertilizer while FYM was free-of-cost (a common practice among the local farmers).

The increase in the agronomic parameters of maize as well as soybean by the use of integrated fertilizer use is accredited to more availability of nitrogen from inorganic, organic, and biological sources throughout the season of the crop. These results have also been found in other studies where it was observed that the application of treatment (50% PM+50% chemical) resulted in supporting plant height of maize as compared to the control plot in the maize-legume cropping system [43]. The increase in the plant growth parameters also seemed more apparent when organic nutrition sources or biofertilizers were used in combination with the inorganic source (NPK fertilizer). The vegetative stage of plants also requires nutrients for better crop stand establishment, and these may have been provided easily by the chemical fertilizers as compared to those by organic sources. Accordingly, the full dose of NPK gave better results than that of sole application of organic sources, but organic sources were combined with biofertilizers; plant growth was the same as that of the full dose of NPK treatment (Table 2-5). These inferences are quite in line with the findings of another report where it was found that integrated use of FYM with that of nitrogen resulted in better plant morphological parameters when compared with the sole application of organic fertilizers [44]. The results are also correlated with the outcomes of other studies in which a high value of the number of leaves and biological yield of the maize crop was noted when the experimental plots were treated with combined fertilizer sources than synthetic fertilizer singly [45, 46]. At one more instance, organic fertilizers applied in conjunction with inorganic sources resulted in synergistic management of nutrients release, improved fertilizer use efficiency, and high yield [47].

Alongside the quantitative parameters, qualitative parameters of the forage were also affected by different nutrition sources (Tables 3-5). A combination of a half dose of NPK with FYM was found the most economical treatment (considering the very low cost of FYM, and the usual practice of unpaid receiving of FYM from other farmers), which gave statistically the same results as that of full doses of NPK. The yield of forage and concentration of protein augmented when full dose NPK, full dose of NPK coated with PGPR, and combined NPK (half dose) with FYM treatment was applied. These outcomes were correlated with the outcomes of Abbasi, Zaghari [48], who detected a significant enhancement in crude protein content with the use of fertilizers as compared to without fertilizer. Similarly, crude protein contents had a considerable increase using synthetic fertilizers and joint use of inorganic with the FYM; the organic source. Nitrogen is contributed critically to the production of amino acids and eventually protein; if high nitrogen is obtainable to the crop, high protein content can be manufactured. Reza, Allahdadi [49] and Abbasi, Zaghari [48] described that the highest level of crude protein content was observed by the use of NPK, which hints at the increase in protein synthesis, which has been recorded in intercropped sorghum with lima bean and amaranth.

Application of the recommended dose of NPK fertilizer amplified ADF and NDF contents too (Table 5). However, unlike other parameters, NPK integrated with FYM caused lesser NDF and ADF contents. These outcomes were correlated with the results of Abbasi, Zaghari [48], who detected an upsurge in NDF contents in the forage of soybean using inorganic fertilizers. Some scientists also observed a significant result which indicated that organic fertilizers decrease ADF contents in maize [50]. On the other hand, the use of PGPR-coated recommended doses of NPK and NPK

integrated with FYM also produced less NDF and ADF contents than other treatments. It can be estimated that fertilizer use influenced the characteristics of the fermentation process of soybean-maize silage, lactic acid reacted in a different way to dissimilar fertilizer supplements. Seglar [51] reported that mostly the existence of a high level of lactic acid proposes an effective fermentation and nominal dry matter loss of silage. The concentration of butyric acid for quality silage should be less than 1 g kg⁻¹ where an increase in its concentration leads to spoilage owing to the secondary fermentation. Kung and Shaver [52] observed that a high concentration of ammonia-N resulted from the hydrolysis of proteins and had an adverse effect on the quality of silage. Therefore, a combination of nutrient sources would be required for good quantity and quality of silage.

5. Conclusions

Intercropping maize with soybean alongside reduced doses of chemical fertilizers integrated with biological as well as organic fertilizers showed the potential of enhancing forage production and quality. Therefore, it can be concluded that biofertilizer-coated chemical fertilizers could be used for obtaining good quantity and quality of forage and silage in the short term. Forthcoming research would be required to evaluate the environmental feasibility and yield potential of various maize hybrids with soybean mixture/intercrop under various ecological zones of the country.

Author Contributions: Conceptualization, A.H. and M.S.I.Z.; methodology, A.H. and M.S.I.Z.; formal analysis, A.H.; writing—original draft preparation, A.H. and M.S.I.Z.; writing—review and editing, A.H., A.T., M.Y., and M.S.I.Z.; supervision, A.T., M.Y., and M.S.I.Z.; project administration, M.S.I.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

6. References

1. Fedoroff, N.V., *Food in a future of 10 billion*. Agriculture & Food Security, 2015. **4**(1).
2. Tilman, D., et al., *Agricultural sustainability and intensive production practices*. Nature, 2002. **418**(6898): p. 671-677.
3. Coulter, J.K., *World Agriculture: Towards 2015/2030. An FAO Perspective*. Edited by J. Bruinsma. Rome: FAO and London: Earthscan (2003), pp. 432, £35.00 Paperback. ISBN 92-5-104835-5. Experimental Agriculture, 2004. **40**(2): p. 269-269.
4. Rehman, A., et al., *Livestock production and population census in Pakistan: Determining their relationship with agricultural GDP using econometric analysis*. Information Processing in Agriculture, 2017. **4**(2): p. 168-177.
5. Kumar, D., R. Singh, and Y. Singh, *Influence of sowing dates and nitrogen scheduling on growth behaviour and productivity of late sown wheat (Triticum aestivum L.) in north Indian plains*. Annals of Agricultural Research, 2016. **37**(1).
6. Coblenz, W.K. and M.S. Akins, *Silage review: Recent advances and future technologies for baled silages*. Journal of Dairy Science, 2018. **101**(5): p. 4075-4092.
7. Raza, A., *Pakistan grain and feed annual: Grain and feed annual 2012*. USDA Foreign Agricultural Service. 2012.
8. Demirel, M., et al., *Effect of Addition of Urea or Urea Plus Molasses to Different Corn Silages Harvested at Dough Stage on Silage Quality and Digestible Dry Matter Yield*. Journal of Applied Animal Research, 2003. **24**(1): p. 7-16.
9. Baghdadi, A., et al., *Impact of organic and inorganic fertilizers on yield and quality of silage corn in intercropped system with soybean*. 2018, PeerJ.

10. Awodun, M.A., *Effect of Poultry Manure on the Growth, Yield and Nutrient Content of Fluted Pumpkin (Telfaria occidentalis Hook F)*. Asian Journal of Agricultural Research, 2007. **1**(2): p. 67-73.
11. Odhiambo, J.J. and V.N. Mag, *An assessment of the use of mineral and organic fertilizers by smallholder farmers in Vhembe district, Limpopo province, South Africa*. African Journal of Agricultural Research, 2008. **3**(5): p. 357-362.
12. Berg, M. and B. Koskella, *Nutrient- and Dose-Dependent Microbiome-Mediated Protection against a Plant Pathogen*. Current Biology, 2018. **28**(15): p. 2487-2492.e3.
13. Ayoola, O. and E. Makinde, *Complementary organic and inorganic fertilizer application: influence on growth and yield of cassava/maize/melon intercrop with a relayed cowpea*. Australian Journal of Basic and Applied Sciences, 2007. **1**(3): p. 187-192.
14. Ronga, D., et al., *Microalgal Biostimulants and Biofertilisers in Crop Productions*. Agronomy, 2019. **9**(4): p. 192.
15. Edmeades, D.C., *The long-term effects of manures and fertilisers on soil productivity and quality: a review*. Nutrient cycling in Agroecosystems, 2003. **66**(2): p. 165-180.
16. Ibrahim, K.H.M. and O.A.S. Fadni, *Effect of Organic Fertilizers Application on Growth, Yield and Quality of Tomatoes in North Kordofan (sandy soil) western Sudan*. Greener Journal of Agricultural Sciences, 2013. **3**(4): p. 299-304.
17. Negassa, W., et al. *Integrated use of organic and inorganic fertilizers for maize production. in Utilization of diversity in land use systems: Sustainable and organic approaches to meet human needs. Conference Tropentag*. 2007.
18. Rochester, I.J., et al., *Using legumes to enhance nitrogen fertility and improve soil condition in cotton cropping systems*. Field Crops Research, 2001. **70**(1): p. 27-41.
19. Ullah, A., et al., *Studies on planting patterns of maize (Zea mays L.) facilitating legumes intercropping*. Journal of Agricultural Research, 2007. **45**(2): p. 113-118.
20. Raza, M.A., et al., *Land productivity and water use efficiency of maize-soybean strip intercropping systems in semi-arid areas: A case study in Punjab Province, Pakistan*. Journal of Cleaner Production, 2021. **308**: p. 127282.
21. Iqbal, M.A., et al., *Agro-botanical response of forage sorghum-soybean intercropping systems under atypical spatio-temporal pattern*. Pakistan Journal of Botany, 2017. **49**(3): p. 987-994.
22. Iqbal, M.A., et al., *Comparative study on temporal and spatial complementarity and profitability of forage sorghum-soybean intercropping systems*. Cust Agronegocio, 2016. **12**: p. 2-18.
23. Khan, M.B. and A. Khaliq, *Production of soybean (Glycine max L.) as cotton based intercrop*. J. Res. Sci, 2004. **15**(01): p. 79-84.
24. Inal, A., et al., *Peanut/maize intercropping induced changes in rhizosphere and nutrient concentrations in shoots*. Plant Physiology and Biochemistry, 2007. **45**(5): p. 350-356.
25. Figueiredo, M., et al., *Potential impact of biological nitrogen fixation and organic fertilization on corn growth and yield in low external input systems*. Corn crop production growth, fertilization and yield. New York: Nova Science Publisher, 2009. **1**: p. 239-267.
26. Backer, R., et al., *Plant Growth-Promoting Rhizobacteria: Context, Mechanisms of Action, and Roadmap to Commercialization of Biostimulants for Sustainable Agriculture*. Frontiers in plant science, 2018. **9**: p. 1473-1473.
27. Mahmood, A., et al., *Seed biopriming with plant growth promoting rhizobacteria: a review*. FEMS Microbiology Ecology, 2016. **92**(8).

28. Oliveira, C.A., et al., *Phosphate solubilizing microorganisms isolated from rhizosphere of maize cultivated in an oxisol of the Brazilian Cerrado Biome*. Soil Biology and Biochemistry, 2009. **41**(9): p. 1782-1787.
29. Kaur, K., K.K. Kapoor, and A.P. Gupta, *Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions*. Journal of Plant Nutrition and Soil Science, 2005. **168**(1): p. 117-122.
30. Nazli, R.I., et al., *Effects of different organic materials on forage yield and nutrient uptake of silage maize (Zea maysL.)*. Journal of Plant Nutrition, 2015. **39**(7): p. 912-921.
31. Ali, W., et al., *Forage Yield and Quality Indices of Silage-Corn Following Organic and Inorganic Phosphorus Amendments in Podzol Soil under Boreal Climate*. Agronomy, 2019. **9**(9): p. 489.
32. Kandil, E.E., et al., *Potentials of organic manure and potassium forms on maize (Zea mays L.) growth and production*. Scientific reports, 2020. **10**(1): p. 8752-8752.
33. Erdal, S., et al., *Silage yield and quality of row intercropped maize and soybean in a crop rotation following winter wheat*. Archives of Agronomy and Soil Science, 2016. **62**(11): p. 1487-1495.
34. Baghdadi, A., et al., *Impact of organic and inorganic fertilizers on the yield and quality of silage corn intercropped with soybean*. PeerJ, 2018. **6**: p. e5280.
35. Rehman, A., et al., *Seed priming of Zn with endophytic bacteria improves the productivity and grain biofortification of bread wheat*. European Journal of Agronomy, 2018. **94**: p. 98-107.
36. Latimer, G., *Official Methods of Analysis of AOAC International*. Gaithersburg, Md.: AOAC International, ISBN: 978-0-935584-83-7. 2012.
37. Cockrell, I., D. Halliday, and D.J. Morgan, *Quality control in the animal feedstuffs manufacturing industry*, H.M.s.S. Office, Editor. 1975: London.
38. Thiex, N., L. Novotny, and A. Crawford, *Determination of Ash in Animal Feed: AOAC Official Method 942.05 Revisited*. Journal of AOAC INTERNATIONAL, 2019. **95**(5): p. 1392-1397.
39. Wilson, R., *A rapid accurate method for measuring volatile fatty acids and lactic acid in silage*. Ruakura: Animal Research Institute, 1971: p. 6-12.
40. Mertens, D.R. and C.A.M.C.J.C.J.D.A.D.M.F.K.G.D.G.M.G.B.J.D.J.C.J.D.K.D.K.G.K. S, *Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: collaborative study*. Journal of AOAC international, 2002. **85**(6): p. 1217-1240.
41. Soest, P.J.V., *Use of Detergents in the Analysis of Fibrous Feeds. II. A Rapid Method for the Determination of Fiber and Lignin*. Journal of AOAC INTERNATIONAL, 1990. **73**(4): p. 491-497.
42. Steel, R.G.D. and J.H. Torrie, *Principles and procedures of statistics: a biometrical approach*. 1986: McGraw-Hill.
43. Mitchell, C.C. and S. Tu, *Long-Term Evaluation of Poultry Litter as a Source of Nitrogen for Cotton and Corn*. Agronomy Journal, 2005. **97**(2): p. 399-407.
44. Khan, A., et al., *Organic and inorganic nitrogen treatments effects on plant and yield attributes of maize in a different tillage systems*. Pak. J. Bot, 2009. **41**(1): p. 99-108.
45. Ibeawuchi, I.I., et al., *Graded replacement of inorganic fertilizer with organic manure for sustainable maize production in Owerri Imo State, Nigeria*. Life Science Journal, 2007. **4**(2): p. 82-87.
46. Lelei, J., R. Onwonga, and B. Freyer, *Organic based nutrient management strategies: effect on soil nutrient availability and maize (Zea mays L.) performance in Njoro, Kenya*. African Journal of Agricultural Research, 2009. **4**(2): p. 092-099.
47. Vanlauwe, B. and K. Giller, *Popular myths around soil fertility management in sub-Saharan Africa*. Agriculture, Ecosystems & Environment, 2006. **116**(1-2): p. 34-46.

48. Abbasi, M., et al., *Is dietary iron requirement of broiler breeder hens at the late stage of production cycle influenced by phytase supplementation?* Journal of Applied Animal Research, 2015. **43**(2): p. 166-176.
49. Reza, Z.O., et al., *Evaluation of quantitative and qualitative traits of forage sorghum and lima bean under different nitrogen fertilizer regimes in additive-replacement series.* Journal of Agricultural Science, 2012. **4**(6): p. 223.
50. Keskin, B., et al., *Effects of urea or urea plus molasses supplementation to silages with different sorghum varieties harvested at the milk stage on the quality and in vitro dry matter digestibility of silages.* Turkish Journal of Veterinary and Animal Sciences, 2005. **29**(5): p. 1143-1147.
51. Seglar, B., *Fermentation analysis and silage quality testing.* 2003.
52. Kung, L. and R. Shaver, *Interpretation and use of silage fermentation analysis reports.* Focus on forage, 2001. **3**(13): p. 1-5.

Table S1 Monthly weather conditions during the maize growth period in 2018 and 2019. The values are average mean for the whole month. Source: Meteorological Cell, University of Agriculture Faisalabad, Pakistan.

| | 2018 | | | | 2019 | |
|--------------------------|--------|-----------|---------|----------|--------|-----------|
| | August | September | October | November | August | September |
| Minimum temperature (°C) | 29.5 | 25.6 | 18.7 | 12.4 | 28.5 | 27.8 |
| Maximum temperature (°C) | 39.0 | 37.2 | 32.6 | 27.0 | 38.0 | 37.7 |
| Relative humidity (%) | 61.0 | 65.1 | 64.4 | 74.6 | 72.5 | 70.1 |
| Rainfall (mm) | 5.4 | 41.7 | 0 | 0.6 | 80.9 | 21.8 |
| Sunshine (hours) | 8.5 | 8.7 | 8.8 | 6.9 | 7.7 | 8.3 |