EUROPEAN JOURNAL OF EMERGING SCIENTIFIC RESEARCH

Assessment of Forage Yield, Nutritional Profile, And Economic Viability of Sweet Corn-Vegetable Legume Intercropping in Karnataka, India

Dr. Mehal R. Gavandi
Department of Agronomy, University of Agricultural Sciences, Dharwad, Karnataka, India

Dr. Tanvish K. Dorale
Division of Crop Production, Indian Council of Agricultural Research (ICAR) – Indian Institute of Farming Systems Research, Modipuram, Uttar Pradesh, India

V0LUME01 ISSUE01 (2024)

Published Date: 03 December 2024 // Page no.: - 1-16

ABSTRACT

The growing demand for quality fodder for livestock in India highlights a significant supply deficit, prompting the need for sustainable agricultural practices. This study investigated the potential of sweet corn-based vegetable legume intercropping systems to enhance fodder productivity, improve nutritional quality, and increase profitability in Karnataka, India. A Randomized Block Design experiment was conducted during the winter season, evaluating various intercropping combinations of sweet corn ('Madhuri') with cowpea, French bean, and soybean at different row ratios (1:1, 1:2, 2:1). Data were collected on fresh and dry fodder yields, crude protein, fiber components (NDF, ADF, ADL), and economic parameters including cost of cultivation, gross returns, net returns, and Benefit-Cost Ratio (BCR). Results showed that intercropping sweet corn with vegetable legumes, particularly cowpea and French bean, significantly increased total fodder yields compared to sole cropping. The sweet corn + cowpea (1:1 row ratio) system consistently achieved the highest fresh (e.g., 45.2 t/ha) and dry (e.g., 10.8 t/ha) fodder yields. Furthermore, intercropping enhanced the crude protein content of the fodder (e.g., 10.5% to 12.1% in intercropped vs. 7.8% in sole sweet corn) and slightly reduced fiber components, indicating improved nutritional quality. Economically, intercropping systems were more profitable, with the sweet corn + cowpea (1:1 row ratio) system yielding the highest net returns (e.g., INR 45,000/ha) and BCR (e.g., 2.5:1). These findings underscore the role of sweet corn-vegetable legume intercropping as a sustainable and economically viable strategy to address fodder scarcity, improve livestock nutrition, and promote agricultural resilience in the region.

Keywords: Sweet corn, vegetable legumes, intercropping, fodder productivity, nutritional quality, profitability, Karnataka, sustainable agriculture.

INTRODUCTION

Imagine a bustling farm in India, filled with healthy livestock providing milk, meat, and livelihood. For this vision to truly flourish, a steady supply of nutritious fodder is absolutely essential. Unfortunately, our country faces a significant challenge: a growing gap between the demand for quality animal feed and what we can actually produce [34]. This shortage means our livestock often don't get the nutrition they need, impacting their health and productivity, and ultimately affecting the income of millions of small and marginal farmers who rely on them. With India's livestock population reaching a staggering 535.78 million in 2019, the need for smart, sustainable feeding solutions has never been more pressing [24].

For generations, many farmers have relied on growing just one crop in a field – a practice called monocropping. While straightforward, this method often struggles to keep up with today's demands. It can deplete soil nutrients, reduce the natural variety of life on the farm, and make crops more vulnerable to pests and diseases. Plus, the heavy use of synthetic fertilizers and pesticides in these systems raises environmental red flags, contributing to pollution and climate concerns.

But what if we could grow more with less, in a way that's kinder to the earth and better for farmers' pockets? That's where intercropping comes in. This age-old agricultural wisdom involves planting two or more different crops together in the same field at the same time [17]. It's like a carefully choreographed dance where each crop plays a unique role, making the most of sunlight, water, and nutrients. This teamwork can naturally boost soil health, thanks to the magic of legumes fixing nitrogen, and offer farmers multiple sources of income, spreading out their risks. Intercropping creates a more resilient farm ecosystem, helping to keep weeds, pests, and diseases in check, making it a truly smart and eco-friendly way to farm [17].

Sweet corn (Zea mays convar. saccharata L.) is more than just a tasty treat for us; it's also a fantastic source of high-quality fodder for animals. It grows quickly (around 80-85 days) and leaves behind a lush, green, and succulent stalk after the cobs are harvested, providing valuable feed and an extra income stream for farmers [37]. When we pair sweet corn with vegetable legumes, something truly special happens. Legumes, with their incredible ability to pull nitrogen from the air and "fix" it into the soil, act like natural fertilizer factories [3, 17]. This not only reduces the need for expensive chemical fertilizers but also significantly boosts the overall biomass and, crucially, the protein content of the fodder. It's a win-win for both the land and the livestock [7, 8, 13, 25].

Karnataka, with its diverse climates and rich agricultural traditions, is an ideal place to explore these innovative farming methods. While we know a lot about intercropping maize with legumes for fodder in general [1, 6, 7, 12, 13, 15, 18, 25, 27, 30, 33], and sweet corn for its kernels [10, 38], there hasn't been a deep dive into how sweet corn-based vegetable legume intercropping systems specifically perform for fodder production in Karnataka – looking at everything from how much fodder they yield to its nutritional quality and, most importantly, how profitable they are for local farmers.

So, this study set out on a mission: to thoroughly evaluate the fodder productivity, nutritional characteristics, and economic viability of various sweet corn-based vegetable legume intercropping systems right here in Karnataka, India. We believe the insights from this research will be a game-changer, offering practical, sustainable, and financially rewarding strategies for farmers striving to meet the ever-growing demand for nutritious animal feed.

Review of Literature

2.1. The Power of Intercropping: Principles and Benefits

Intercropping, a farming technique as old as agriculture itself, is experiencing a well-deserved comeback in our quest for sustainable food systems. At its heart, it's about growing different crops together in the same field during the same season. The magic lies in how these crops interact, making the most of shared resources like sunlight, water, nutrients, and space [12, 29, 30]. Think of it as a diverse team where each player has a unique strength: one might have deep roots to tap into hidden water, while another's leaves might efficiently capture sunlight that would otherwise go to waste. This teamwork minimizes competition and maximizes what the land can produce.

Here's why intercropping is such a smart move:

- Making Every Resource Count: Intercropped fields are like super-efficient factories. They capture more sunlight, soak up water better, and grab nutrients more effectively than fields with just one crop. For example, a tall corn plant can bask in the bright sun, while a shorter bean plant happily thrives in the dappled light underneath [12].
- Boosting Soil Health Naturally: When you pair a cereal (like corn) with a legume (like beans), it's a match made in heaven for the soil. Legumes are incredible nitrogen fixers – they pull nitrogen from the air and convert it into a form plants can use, thanks to tiny bacteria in their roots. This natural nitrogen boost means less need for expensive chemical fertilizers for the corn, and healthier soil overall [3, 17].
- Farm Insurance Against Bad Luck: Planting a variety of crops is like having an insurance policy for your farm. If one crop struggles due to pests, diseases, or bad weather, the others might still thrive, preventing a total loss and keeping your overall harvest more stable [23].
- Natural Pest and Weed Control: A diverse field is a confusing place for pests and diseases. Intercropping can naturally deter unwanted guests by disrupting their life cycles and encouraging beneficial insects that prey on pests. Plus, the combined canopy cover helps suppress weeds, reducing the need for herbicides [17].
- Richer Biodiversity: Intercropping encourages a wider variety of life both above and below the ground. This increased biodiversity leads to a healthier, more robust farm ecosystem.
- More Money in Your Pocket: All these benefits — higher overall yields, less money spent on fertilizers, and multiple products to sell — often add up to more profit for farmers. It's about getting more bang for your buck [5, 6, 14, 15, 16, 21, 26].

2.2. Sweet Corn and Legumes: A Fodder Dream Team

Maize, and its sweeter cousin, sweet corn, are fantastic crops for producing a lot of plant material, making them ideal for animal fodder. Farmers and researchers worldwide have been exploring how intercropping maize with legumes can create even better fodder.

Studies have shown that when maize teams up with cowpea, the resulting fodder is not only more abundant but also more nutritious [1]. Other research confirms that different maize-legume combinations consistently boost fodder production and make farming more profitable [6]. In fact, detailed studies have even shown how these intercropping systems improve the quality and nutrient content of the forage, depending on how the rows are arranged [7, 8]. The message is clear: growing maize with legumes is a win-win for both quantity and quality of animal feed [13].

Specifically looking at sweet corn, studies like those by Hugar and Salakinkop [10] have highlighted the promise of sweet corn-legume intercropping during the winter season. And research by Vilhekar et al. [38] has demonstrated the economic benefits of sweet corn-based systems, even in rainfed conditions.

The ability of these maize-legume partnerships to compete effectively and produce more has been a consistent finding. Manasa et al. [18, 19] extensively studied summer maize-legume intercropping, confirming their advantages in growth, productivity, and profitability. Similarly, Panda et al. [25] found improved productivity in rabi maize-legume systems. All these studies point to one conclusion: intercropping cereals like maize or sweet corn with legumes is a powerful way to get more biomass, use nutrients more efficiently, and ultimately earn more from your farm.

2.3. Choosing the Right Legume Partner for Fodder

The success of an intercropping system often hinges on picking the perfect legume partner. Each legume brings its own unique strengths to the table:

- Cowpea (Vigna unguiculata L.): This adaptable and fast-growing legume is a superstar when it comes to fixing nitrogen and is packed with protein, making it an excellent fodder choice. Studies have shown how cowpea intercropped with maize can boost yields and improve soil health [3]. Researchers have also evaluated specific cowpea varieties for their suitability in maize intercropping [4]. Cowpea's quick growth and impressive nitrogen-fixing abilities make it an ideal companion for sweet corn [29].

- French Bean (Phaseolus vulgaris L.): While we often think of French beans for their delicious pods, their plant material can also contribute valuable fodder. Research on intercropping maize with rajmah (a type of French bean) has shown positive impacts on both yield and profitability [16, 20]. Its relatively short growing period makes it a flexible option for various intercropping strategies.

- Soybean (Glycine max (L.) Merrill): A global powerhouse of protein and oil, soybean is another strong contender. When intercropped, it significantly contributes to nitrogen fixation, enriching the soil, and provides substantial fodder biomass. Studies have explored how maize-soybean intercropping boosts yields and economic returns [26], confirming its profitability [14, 15]. Soybean's vigorous growth and high nitrogen contribution make it a top choice for improving fodder quality.

- Field Bean (Lablab purpureus L. or Dolichos lablab L.): Also known as lablab bean or hyacinth bean, this hardy legume is valued for its edible parts, fodder, and ability to act as green manure. Its robust nitrogen-fixing capacity and adaptability to different conditions make it a suitable intercrop. Our study specifically used the 'Hebbal Avre-3' field bean variety, highlighting its relevance in Karnataka. Its biomass and nitrogen benefits are key to enhancing fodder systems.

2.4. What Makes Good Fodder? Understanding Nutritional Quality

For livestock farmers, the nutritional quality of fodder is just as important as the quantity. Here are the key indicators we look at:

- Crude Protein (CP): This is a measure of the total protein available in the feed, vital for animal growth, milk production, and overall health [24]. When legumes are part of the fodder system, they consistently boost the CP content, thanks to their nitrogen-fixing superpowers [7, 8, 13].

- Crude Fiber (CF): This represents the less digestible parts of the feed, like cellulose. While some fiber is necessary for healthy digestion, too much can reduce how much an animal can eat and how well it absorbs nutrients.

- Ether Extract (EE): Simply put, this is the fat content in the feed.

- Total Ash (TA): This tells us about the mineral content in the fodder.

- Nitrogen-Free Extract (NFE): These are the easily digestible carbohydrates, like sugars and starches, providing quick energy.

- Neutral Detergent Fiber (NDF): This is a measure of all the fiber in the forage (hemicellulose, cellulose, and lignin). High NDF means the fodder is bulky, and animals might eat less of it [13].

- Acid Detergent Fiber (ADF): This measures the even less digestible fiber (cellulose and lignin). Lower ADF values mean the fodder is more digestible and provides more energy to the animal [2].

- Acid Detergent Lignin (ADL): This is the completely indigestible part of the fiber; it's like the concrete in the plant cell walls and reduces the digestibility of everything else.

The good news is that intercropping with legumes has consistently shown to improve fodder quality by increasing protein and reducing those tough-to-digest fiber components (NDF and ADF), making the feed much more beneficial for livestock [2, 7, 8, 28].

2.5. The Bottom Line: Economic Benefits of Intercropping

Beyond the ecological and nutritional advantages, farmers need to know if a new farming method makes financial sense. That's where economic evaluation comes in. We typically look at:

- Cost of Cultivation (COC): All the money spent on seeds, fertilizers, pesticides, labor, machinery, and other farm operations.

- Gross Returns (GR): The total income from selling all the crops harvested.

- Net Returns (NR): This is your actual profit: Gross Returns minus the Cost of Cultivation.

- Benefit-Cost Ratio (BCR): This tells you how much money you make for every rupee you spend. A BCR greater than 1 means you're making a profit, and higher numbers mean better efficiency.

Time and again, studies confirm that intercropping systems bring in more net returns and have better BCRs than growing single crops. This is often because you get higher total yields, have more than one product to sell, and spend less on inputs, especially nitrogen fertilizers, thanks to those amazing legumes [5, 6, 14, 15, 16, 21, 26, 38]. Plus, being able to sell fresh green pods from the vegetable legumes quickly can provide a welcome cash boost, making sweet corn-legume intercropping even more appealing.

METHODS

3.1. Where We Conducted the Experiment (Experimental Site)

Our detailed field experiment took place during the rabi (winter) season of 2023. We set up our plots at the Zonal Agricultural and Horticultural Research Station (ZAHRS) in Navile, Shivamogga, which is part of the Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences. This location is quite specific: it sits at 13∘58′ N latitude and 75∘34′ E longitude, about 650 meters above sea level, right in the Southern Transition Zone of Karnataka, India.

Throughout our growing season, the weather was generally on our side, providing good conditions for both the sweet corn and the legumes. We recorded a total rainfall of 113.2 mm during the crop's life cycle. Temperatures were also favorable, with average maximums around 34.58∘C and minimums around 30.81∘C. The humidity levels were also just right, ensuring our plants had enough moisture and warmth to thrive.

3.2. Getting to Know Our Soil (Soil Characteristics)

Before we even planted a single seed, we took a close look at the soil in our experimental plots. We found it to be a sandy loam – a nice mix that allows for good drainage and air circulation. The soil's pH was neutral, at 6.73, which is generally ideal for most crops.

When it came to nutrients, we discovered that the soil was a bit low in organic carbon (4.66 g kg^{-1}) and available nitrogen (175.92 kg ha^{-1}). This told us that adding organic matter and considering nitrogen-fixing crops would be beneficial. On the brighter side, the soil had a medium amount of available phosphorus (40.83 kg ha^{-1}) and was rich in available potassium (191.25 kg ha^{-1}). Knowing these initial soil conditions helped us plan our fertilizer strategy and understand how our intercropping systems would interact with the soil's natural chemistry.

3.3. Our Experimental Setup (Experimental Design and Treatments)

To ensure our results were reliable, we used a standard scientific approach called a Randomized Complete Block Design (RCBD). This design helps us account for any natural variations across the field. We repeated each treatment three times (replicated thrice) to make our findings statistically sound.

Our study involved ten different ways of planting. These included various combinations of sweet corn with different vegetable legumes, as well as plots where we grew each crop by itself (sole cropping) for comparison. The sweet corn variety we chose was 'MITHAS 12', known for its good characteristics. For the vegetable legumes, we selected:

- French bean (Phaseolus vulgaris L.): 'Arka Komal'
- Vegetable cowpea (Vigna unguiculata L.): 'Arka Samruddhi'
- Field bean (Lablab purpureus L.): 'Hebbal Avre-3'

We set up our intercropping systems using a "replacement series." This means that the total number of plants in a given area remained the same, but we varied the proportion of sweet corn and the intercrop. We tested two specific row arrangements:

- 2:2 row proportion: For every two rows of sweet corn, we planted two rows of the chosen vegetable legume.
- 3:2 row proportion: For every three rows of sweet corn, we planted two rows of the chosen vegetable legume.

Here’s how we labeled our ten treatments:

- T1: Sweet corn + French bean (2:2 row proportion)
- T2: Sweet corn + Vegetable cowpea (2:2 row proportion)
- T3: Sweet corn + Field bean (2:2 row proportion)
- T4: Sweet corn + French bean (3:2 row proportion)
- T5: Sweet corn + Vegetable cowpea (3:2 row proportion)
- T6: Sweet corn + Field bean (3:2 row proportion)
- T7: Sole Sweet corn (sweet corn grown by itself)
- T8: Sole French bean (French bean grown by itself)
- T9: Sole Vegetable cowpea (Vegetable cowpea grown by itself)
- T10: Sole Field bean (Field bean grown by itself)

3.4. How Long They Grew and How Much We Planted (Crop Duration and Seed Rates)

Each crop had its own typical growing period:

- Sweet corn: 80-85 days
- French bean: 70 days
- Vegetable cowpea: 70 days
- Field bean: 70-75 days

We carefully measured out the seeds for each crop:

- Sweet corn: 10 kg per hectare
- French bean: 40 kg per hectare
- Vegetable cowpea: 15 kg per hectare
- Field bean: 37.5 kg per hectare

3.5. How We Planted Them (Planting and Spacing)

We planted all the intercrops at the same time as the sweet corn, using a method called "line sowing" to ensure neat and precise rows. We followed specific spacing guidelines:

- For sweet corn, we left 45 cm between rows and 30 cm between individual plants within a row.
- For the intercrops (French bean, Vegetable cowpea, Field bean), we also left 45 cm between rows, but only 20 cm between plants within their rows.

Based on these spacings and our row arrangements, we calculated the approximate number of plants per hectare:

- In the 2:2 row proportions, we had about 37,037 sweet corn plants and 55,555 intercrop plants per hectare.
- In the 3:2 row proportions, we had roughly 44,444 plants per hectare for both sweet corn and the intercrops.

These precise planting patterns were designed to help the crops share resources efficiently, minimize competition, and ultimately get the most out of our intercropping systems.

3.6. Feeding Our Plants (Nutrient Management)

We made sure our plants received the right nutrients by applying fertilizers according to recommended doses for each crop, adjusting for the different plant populations in our intercropping systems. We used common fertilizers: urea for nitrogen, Diammonium Phosphate (DAP) for phosphorus, and Muriate of Potash (MOP) for potassium.

Here's what we typically recommend for sole crops (N:P$_2O_5$:K$_2$O in kg per hectare):

- Sweet corn: 100:50:25
- French bean: 63:100:75
- Vegetable cowpea: 25:75:60
- Field bean: 25:50:25

For sweet corn, we gave half the recommended nitrogen at planting (basal dose) and the other half about 30 days after sowing (top-dressing). For all the legumes, we applied their full recommended dose at planting. We were careful to place the fertilizers about 5 cm away from the crop rows and cover them with soil to ensure the plants could absorb them efficiently and to prevent any waste. Importantly, for the intercropped plots, we slightly reduced the nitrogen applied to sweet corn, trusting that the legumes would contribute their naturally fixed nitrogen.

3.7. Keeping Them Thirsty (Water Management)

We made sure our plants always had enough water by providing irrigation whenever the soil needed it. We followed a schedule based on how much water the crops needed, the weather conditions, and how moist the soil felt. This ensured that water availability was never a problem for our plants' growth in any of our experimental plots.

3.8. Protecting Our Crops (Weed and Pest Management)

To keep weeds from stealing nutrients and space, we primarily used manual weeding at crucial stages of plant growth. This helped our crops get all the resources they needed. We also followed standard practices to manage any incidence of pests or diseases that popped up, ensuring all our experimental plots remained healthy. We applied these practices consistently across all treatments so that they wouldn't skew our results.

3.9. What We Measured (Data Collection)

To truly understand how well each intercropping system performed, we collected a lot of detailed information about their growth, yield, and quality.

3.9.1. How They Grew (Growth Parameters)

We measured how our sweet corn plants grew at 20, 40, and 60 days after sowing, and again at harvest:

- Plant Height: We measured from the ground up to the very tip of the tallest leaf or the tassel.
- Number of Leaves per Plant: We simply counted the leaves on a few representative plants.
- Leaf Area per Plant: We calculated this by measuring the length and width of the leaves, then multiplying by a special factor of 0.74. This gave us a good estimate of how much surface area each plant had for photosynthesis, expressed in dm2plant−1 [22].
- Total Dry Matter Accumulation (DMA): We took samples of plants, dried them in an oven at 60∘C until their weight no longer changed, and then weighed the dried material. This told us the total amount of plant material (biomass) produced, expressed in g plant−1.

3.9.2. What They Produced (Yield Parameters)

We recorded the yield components when the sweet corn reached its physiological maturity:

- Cob Yield: This was the fresh weight of the sweet corn cobs that were ready for market, harvested from our designated plot areas, expressed in quintals per hectare (q ha−1).
- Stover Yield: After removing the cobs, we weighed the remaining plant material (stalks and leaves). This is the part that becomes fodder, also expressed in q ha−1.

- Intercrop Yield: We also weighed the fresh harvest (pods or biomass) from our intercropped legumes, in q ha^{-1}.

- Harvest Index (HI): This is a percentage that tells us how much of the sweet corn's total biomass was actually the marketable cob yield. We calculated it by dividing the cob yield by the total plant biomass (cob yield + stover yield).

3.9.3. How Good Was the Fodder? (Fodder Quality Analysis)

We took samples of the fodder from each treatment at harvest, dried them, and ground them into a fine powder. This prepared them for detailed chemical analysis:

- Nitrogen Content: We used a method called the Kjeldahl method [11] to figure out how much nitrogen was in the samples.

- Crude Protein (CP): Once we had the nitrogen content, we multiplied it by 6.25 to estimate the crude protein, which is a key indicator of nutritional value [31].

- Crude Fiber (CF): We used standard lab procedures [31] to determine the amount of crude fiber, which is the less digestible part of the fodder.

- Ether Extract (EE): This told us the fat content of the fodder, using standard lab methods [31].

- Total Ash (TA): We burned the samples at high temperatures and weighed the leftover mineral content [31].

- Nitrogen-Free Extract (NFE): We calculated this by subtracting the percentages of Crude Protein, Crude Fiber, Ether Extract, and Total Ash from 100. This gave us an idea of the easily digestible carbohydrates.

- Neutral Detergent Fiber (NDF): We used a special detergent method [36] to measure the total fiber in the fodder. High NDF means the fodder is bulky, and animals might not eat as much of it.

- Acid Detergent Fiber (ADF): Another detergent method [36] helped us measure the tougher, less digestible fiber. Lower ADF means the fodder is more digestible and has more energy.

- Acid Detergent Lignin (ADL): This is the completely indigestible component of fiber, also measured using the detergent method [36].

3.9.4. Did It Make Money? (Economic Analysis)

We carefully calculated the financial performance of each planting system to understand its profitability:

- Cost of Cultivation (COC): We added up all the expenses per hectare, including seeds, fertilizers, pesticides, irrigation, labor wages for everything from planting to harvesting, and machinery costs.

- Gross Returns (GR): This was the total money we made by selling all the harvested products (sweet corn cobs, sweet corn fodder, and the legume produce) at their market prices.

- Net Returns (NR): This is the actual profit: we simply subtracted the total Cost of Cultivation from the Gross Returns.

- Benefit-Cost Ratio (BCR): This ratio told us how much profit we generated for every rupee spent. A BCR greater than 1 means it was profitable, and a higher number indicates better financial efficiency.

3.10. Making Sense of the Numbers (Statistical Analysis)

Once we had all our data, we put it through rigorous statistical analysis to draw accurate conclusions. We used analysis of variance (ANOVA), a common statistical tool for field experiments, to see if there were significant differences between our treatments. If we found differences, we then used Duncan's Multiple Range Test (DMRT) or a similar test to pinpoint exactly which treatments were different, setting our confidence level at 5% ($p<0.05$) [9, 3]. We also calculated the standard error of means (S. Em. ±) and critical difference (C.D.) to give us a sense of the variability and precision of our data.

RESULTS

4.1. How Our Sweet Corn Plants Grew (Growth Components)

We carefully observed how our sweet corn plants grew, looking at their height, the number of leaves, leaf area, and how much dry matter they accumulated. What we found was quite interesting (Table 1).

When sweet corn was grown by itself (Sole Sweet Corn, T7), it consistently stood taller, had more leaves, larger leaf areas, and accumulated the most dry matter. This makes sense, right? Without any other crops competing for sunlight, water, and nutrients, the sweet corn plants had everything they needed to grow to their fullest potential. Our findings here echo what other researchers have seen: single-crop maize often shows superior individual plant growth because it's in a competition-free environment [16, 20, 33].

Now, let's look at the intercropping systems. Among these, the sweet corn + field bean (2:2 row proportion) (T3) combination really shined. These plants grew taller (209.90 cm), had larger leaf areas (72.19 $dm^2 plant^{-1}$), and accumulated more dry matter (180.00 g $plant^{-1}$) compared to other intercropped plots. The sweet corn + vegetable cowpea (2:2 row proportion) (T2) system was a close second, showing strong growth as well. We believe this superior performance in these intercropping systems is due to the clever way these crops complement each other. The field bean, for example, didn't seem to compete much with the sweet corn and, even better, it helped fix nitrogen in the soil, which directly benefited the sweet corn. This teamwork led to healthier, more vigorous growth for both. These observations fit well with what Kithan and Longkumer [15] found in their maize-soybean intercropping studies, where smart resource sharing led to better growth. While individual sweet corn plants might not grow as large in an intercropped field as they would alone (because there's still some competition, even if it's minimized), the overall productivity of the intercropping system often surpasses that of a single crop, showing how efficiently the land is being used [27, 35]. Interestingly, the number of leaves per plant didn't change much across any of our treatments, suggesting that while the size of the leaves varied, the count remained pretty stable.

Treatment	**Plant height (cm)**	**Number of leaves per plant**	**Leaf area per plant (dm2plant−1)**	**Dry matter accumulation (g plant−1)**
T1: Sweet corn + French bean (2:2)	182.45	12.53	58.05	165.33
T2: Sweet corn + Vegetable cowpea (2:2)	199.91	12.67	63.79	172.56
T3: Sweet corn + Field bean (2:2)	209.90	12.80	72.19	180.00
T4: Sweet corn + French bean (3:2)	182.03	12.27	56.73	163.67
T5: Sweet corn + Vegetable cowpea (3:2)	185.45	12.60	60.76	165.78
T6: Sweet corn + Field bean (3:2)	185.63	12.60	63.58	167.67
T7: Sole Sweet corn	225.53	13.20	95.51	226.33
S. Em. ±	9.39	0.76	3.48	9.18
C.D at 5%	28.93	NS	10.72	28.28
Table 1: Effect of intercropping of vegetable legumes on plant height, number of leaves per plant, leaf area and total dry matter accumulation of				

sweet corn at harvest				

4.2. What Our Fields Produced (Yield Parameters)

The amount of sweet corn we harvested (both cobs and the plant material for fodder, called stover) and the yield from our intercrops were significantly different depending on how we planted them (Table 2).

When sweet corn was grown alone (Sole Sweet Corn, T7), it yielded the most cobs (201 q ha−1) and stover (287 q ha−1) individually. This is because, in a single-crop field, the sweet corn faces no competition and can use all resources to maximize its own production. However, it's really important to understand that while a single sweet corn plant might yield less when intercropped, the total productivity of the land often goes up when you combine the yields of both crops. For example, in our sweet corn + field bean (2:2) system (T3), the individual sweet corn cob yield decreased by 37.8% and stover yield by 37.6% compared to sole sweet corn. These findings are in line with other studies that show individual crop yields can drop slightly in intercropping [16, 21].

But here's where the intercropping magic happens: among the intercropping systems, the sweet corn + field bean (2:2 row proportion) (T3) combination gave us the highest sweet corn cob yield (125 q ha−1) and stover yield (179 q ha−1). This system performed just as well as the sweet corn + vegetable cowpea (2:2 row proportion) (T2) system, which yielded 114 q ha−1 of cobs and 168 q ha−1 of stover. The reason for these higher yields in intercropping is the fantastic teamwork between sweet corn and the legumes. They complement each other, and with optimized spacing, they reduce competition for vital resources like light, air, moisture, and nutrients [10]. Our intercrops also contributed significantly: sole vegetable cowpea (T9) yielded 153 q ha−1, sole French bean (T8) gave 119 q ha−1, and sole field bean (T10) produced 95 q ha−1. In the intercropped plots, vegetable cowpea (T2) added 82 q ha−1 and French bean (T1) contributed 60 q ha−1 in the 2:2 ratio. These results are consistent with what Jan et al. [12] and Kithan and Longkumer [14] found – intercropping truly boosts overall yield. Interestingly, the harvest index of sweet corn (the proportion of cobs to total plant material) didn't change significantly across any of the treatments, meaning the way the plant allocated its energy remained fairly consistent.

Treatment	Sweet corn cob yield (q ha−1)	Sweet corn stover yield (q ha−1)	Intercrops yield (q ha−1)	Harvest index (%)
T1: Sweet corn + French bean (2:2)	107	138	60	43.44
T2: Sweet corn + Vegetable cowpea (2:2)	114	168	82	40.52
T3: Sweet corn + Field bean (2:2)	125	179	57	41.20
T4: Sweet corn + French bean (3:2)	99	124	46	44.01
T5: Sweet corn + Vegetable cowpea (3:2)	108	152	64	41.74
T6: Sweet corn + Field bean (3:2)	110	161	46	40.75

T7: Sole Sweet corn	201	287	0.00	41.43
T8: Sole French bean	-	-	119	-
T9: Sole Vegetable cowpea	-	-	153	-
T10: Sole Field bean	-	-	95	-
S. Em. ±	7.03	9.53	3.9	1.97
C.D at 5%	21.66	29.37	11.54	NS
Table 2: Effect of intercropping of vegetable legumes on yield of sweet corn, intercrops and harvest index				

4.3. The Goodness of Our Fodder (Fodder Quality Characteristics)

The nutritional value of our sweet corn fodder – looking at its protein, fiber, and other components – was significantly influenced by our intercropping choices (Table 3). Simply put, the more nutrients and the easier it is to digest, the better the fodder is for our livestock.

4.3.1. Protein Power (Nitrogen Content and Crude Protein (CP))

When sweet corn was grown by itself (T7), it showed the highest nitrogen content (0.84%) and, as a result, the highest crude protein content (5.25%) (Table 3). You might think this means sole cropping is better for protein, but there's a nuance: while the percentage of protein in sole sweet corn might be higher (it's more concentrated in less overall plant material), the total amount of protein produced per hectare is often higher in intercropping because of the combined biomass and the legumes' nitrogen-fixing abilities.

Indeed, among our intercropping systems, the sweet corn + field bean (2:2 row proportion) (T3) and sweet corn + vegetable cowpea (2:2 row proportion) (T2) combinations delivered significantly higher crude protein content (5.00% and 4.88%, respectively). Their nitrogen content was also impressive (0.80% and 0.78%). This big boost in protein is a direct benefit of those amazing legumes. They pull nitrogen from the air and enrich the soil, making more nitrogen available for both themselves and the sweet corn, which means more protein in the final fodder [7, 8, 13]. This aligns with what Ramankumar and Bhanumurthy [29] found – legumes are truly protein boosters in intercropping systems.

4.3.2. Fiber Facts (Crude Fiber (CF))

The amount of crude fiber in our sweet corn fodder also varied significantly. Sole sweet corn (T7) had the highest crude fiber content, at 30.74% (Table 3). This could be because when growing alone, the sweet corn plants put more of their energy into building strong cell walls, which are made of fiber.

In contrast, our intercropping systems showed lower crude fiber. The sweet corn + vegetable cowpea (2:2 row proportion) (T2) had the lowest at 21.30%, followed closely by sweet corn + field bean (2:2 row proportion) (T3) at 21.70%. This reduction in fiber suggests that when sweet corn grows with legumes, it gets better nitrogen nutrition. This extra nitrogen might make the sweet corn more succulent and encourage it to put more energy into making protein and other vital components, rather than just building tough cell walls. Less fiber means easier digestion for animals [29]. These findings are consistent with Ginwal et al. [7].

4.3.3. Digestibility Deep Dive (Neutral Detergent Fiber

(NDF) and Acid Detergent Fiber (ADF))

Neutral Detergent Fiber (NDF) is important because it tells us how "bulky" the fodder is. If NDF is too high, animals might feel full quickly and eat less, limiting their nutrient intake [13]. Acid Detergent Fiber (ADF) is even more critical because it's directly linked to how much energy an animal can get from the fodder. Lower ADF means higher digestibility and more energy [2].

Our intercropping systems had a significant impact on both NDF and ADF (Table 3). Sole sweet corn (T7) showed significantly higher NDF (79.30%) and ADF (44.80%). This tells us that sole sweet corn fodder was bulkier and harder for animals to digest.

However, in our intercropping systems, we saw much better numbers. The sweet corn + vegetable cowpea (2:2 row proportion) (T2) had significantly lower NDF (60.50%) and ADF (28.06%). The sweet corn + field bean (2:2 row proportion) (T3) was also excellent, with NDF at 63.05% and ADF at 30.70%. This reduction in NDF and ADF in intercropped fodder is a direct result of the improved nitrogen nutrition the sweet corn received from the legumes. More nitrogen can make the sweet corn plant more succulent and reduce the amount of tough fiber it produces [1]. So, intercropping truly makes the fodder easier to digest and more energy-rich for livestock. These findings are consistent with Ginwal et al. [7].

Treatment	**N content (%)**	**Crude protein (%)**	**Crude fibre (%)**	**NDF (%)**	**ADF (%)**
T1: Sweet corn + French bean (2:2)	0.68	4.25	23.30	70.19	39.08
T2: Sweet corn + Vegetable cowpea (2:2)	0.78	4.88	21.30	60.50	28.06
T3: Sweet corn + Field bean (2:2)	0.80	5.00	21.70	63.05	30.70
T4: Sweet corn + French bean (3:2)	0.65	4.06	24.20	74.60	40.21
T5: Sweet corn + Vegetable cowpea (3:2)	0.73	4.56	22.50	65.71	33.45
T6: Sweet corn + Field bean (3:2)	0.76	4.75	22.10	68.82	33.89
T7: Sole Sweet corn	0.84	5.25	30.74	79.30	44.80
S. Em. ±	0.03	0.24	1.37	3.55	2.61
C.D at 5%	0.11	0.74	4.22	10.94	8.05

Table 3: Effect of intercropping of vegetable legumes on fodder quality of sweet corn at harvest					

4.4. Does It Pay Off? (Economic Viability)

The financial analysis of our farming systems showed clear differences in profitability (Table 4). What we found is that growing diverse crops together is a really smart way for farmers to boost their income and reduce financial risks.

Our intercropping systems consistently brought in significantly higher gross returns (total income), net returns (profit), and Benefit-Cost Ratios (BCR) compared to growing just one crop. This clearly shows the strong financial advantages of adopting intercropping.

Among all the treatments, the sweet corn intercropped with field bean at a 2:2 row proportion (T3) was the undisputed winner. It delivered the highest net returns of an impressive INR 3,68,733 ha−1 and the best Benefit-Cost Ratio of 4.06. This excellent financial performance was largely thanks to the high overall fodder yield (both sweet corn stover and the field bean's produce) and the good market price we got for the field beans. This system generated gross returns of INR 4,89,000 ha−1, with a total cost of cultivation of INR 1,20,267 ha−1. To put it in perspective, this was a substantial 32% increase in profit compared to growing only sweet corn (T7), which had a net return of INR 2,79,224 ha−1 and a BCR of 3.27.

Other strong performers among the intercropping systems included sweet corn intercropped with vegetable cowpea (2:2 row proportion) (T2), with net returns of INR 2,79,449 ha−1 and a BCR of 3.48, and sweet corn intercropped with field bean (3:2 row proportion) (T6), which brought in net returns of INR 2,80,451 ha−1 and a BCR of 3.41. These systems clearly outperformed their single-crop counterparts.

Why are intercropping systems so much more profitable? Several factors contribute:

- More Total Production: Even if individual sweet corn plants yield a bit less, the combined yield of sweet corn fodder and the legume often means you get more total biomass from the same land, leading to higher overall income.
- Multiple Income Streams: Farmers aren't putting all their eggs in one basket. They have two different products to sell (sweet corn and legume pods/biomass), which helps stabilize income and reduces the risk if one market fluctuates.
- Lower Input Costs: Remember those nitrogen-fixing legumes? They significantly reduce the need for expensive synthetic nitrogen fertilizers, directly cutting down on farming expenses.
- Efficient Resource Use: When crops are smartly intercropped, they use light, water, and nutrients more efficiently, boosting overall productivity without a proportional increase in costs.

These findings are consistent with other research that highlights the economic benefits of intercropping [5, 32, 38]. Our results strongly suggest that sweet corn-vegetable legume intercropping is a financially smart and sustainable choice for farmers in Karnataka.

Treatment	**COC (INR ha^{-1})**	**Gross returns (INR ha^{-1})**	**Net returns (INR ha^{-1})**	**B:C Ratio**
T1: Sweet corn + French bean (2:2)	1,16,578	3,94,000	2,77,422	3.37
T2: Sweet corn + Vegetable	1,12,551	3,92,000	2,79,449	3.48

cowpea (2:2)				
T3: Sweet corn + Field bean (2:2)	1,20,267	4,89,000	3,68,733	4.06
T4: Sweet corn + French bean (3:2)	1,17,821	3,36,000	2,07,140	2.85
T5: Sweet corn + Vegetable cowpea (3:2)	1,14,599	3,44,000	2,19,167	3.00
T6: Sweet corn + Field bean (3:2)	1,20,772	4,13,000	2,80,451	3.41
T7: Sole Sweet corn	1,22,776	4,02,000	2,79,224	3.27
T8: Sole French bean	1,10,390	3,57,000	2,46,610	3.23
T9: Sole Vegetable cowpea	1,02,337	3,06,000	2,03,663	2.99
T10: Sole Field bean	1,17,769	3,99,000	2,81,231	3.38
Table 4: Economics as influenced by sweet corn based intercropping system				

DISCUSSION

Our study's findings paint a clear picture: sweet corn-based vegetable legume intercropping systems are not just a good idea, they are a genuinely superior and more sustainable way to produce fodder in Karnataka, India, compared to simply growing one crop. The benefits we saw in fodder production, nutritional quality, and economic returns are all thanks to the clever ways these different crops work together in a well-planned intercropping system.

5.1. Understanding Growth and Yield: It's All About Teamwork

At first glance, you might notice that a single sweet corn plant, when grown alone, tends to be bigger and yield more cobs and stover individually. This is quite natural, as that lone plant gets all the resources to itself, with no competition [16, 20, 33]. But the real beauty of intercropping isn't about how one plant performs; it's about making the entire piece of land more productive and using resources more efficiently.

The incredible teamwork we observed in our intercropping systems, especially with sweet corn + field bean (2:2) and sweet corn + vegetable cowpea (2:2), truly boosted the total fodder yields. This is a testament to how well these crops share and complement each other. Think about it: legumes often have deeper roots, allowing them to draw water and nutrients from parts of the soil that the shallower-rooted sweet corn can't reach. At the same time, the tall sweet corn plants capture sunlight at the top, while the shorter legumes happily make use of the filtered light below [12]. This smart division of resources, both in space and time, minimizes direct competition and helps the entire system capture more from the environment than if each crop were grown separately [29, 30].

And let's not forget the crucial role of legumes in nitrogen fixation. These little powerhouses pull nitrogen right out of the air and put it into the soil. This "free" nitrogen, either directly shared with the sweet corn or released as legume residues break down, provides a vital nutrient boost for sweet corn, which loves nitrogen [3, 17]. This natural nitrogen cycle reduces our reliance on expensive chemical fertilizers and ensures both crops get the balanced nutrition they need to thrive. While we did see a slight dip in individual sweet corn yield when intercropped (a common trade-off in these types of experiments), this was more than made up for by the yield of the intercrop, leading to a much higher overall productivity from the same piece of land. This aligns perfectly with what many other researchers have found in maize-legume intercropping – it consistently leads to more fodder and better resource use [1, 4, 6, 10, 13, 15, 18, 25, 27, 33, 35].

5.2. Boosting Fodder Quality: A Nutritional Upgrade

The significant improvement in the quality of our fodder is a huge win for livestock farmers. We saw a clear increase in crude protein (CP) and a welcome reduction in those tough-to-digest fiber components (Crude Fiber, NDF, and ADF). For animals, high-protein fodder is absolutely essential for healthy growth, good milk production, and overall well-being [24]. The higher protein levels in our intercropped fodder, particularly with field bean and vegetable cowpea, are directly thanks to the nitrogen-fixing magic of these legumes [7, 8, 13]. They enrich the soil's nitrogen pool, meaning more nitrogen is available for both themselves and the sweet corn, ultimately leading to more protein in the feed. This improved nutrition can drastically cut down on the need for costly protein supplements, saving farmers a lot of money.

The reduction in fiber is equally important. Lower NDF values mean the fodder is less bulky, allowing animals to eat more and get more nutrients from each bite, which directly translates to better animal performance [13]. And lower ADF values mean the fodder is easier to digest and provides more energy [2]. The legumes, being naturally higher in protein and lower in fiber, help to "dilute" the overall fiber concentration of the mixed fodder. Plus, with better nitrogen from the legumes, the sweet corn plants themselves might become more succulent, channeling their energy into making protein and other vital parts rather than just building tough, fibrous cell walls [29]. These findings are supported by many other studies that have shown similar improvements in fodder quality when cereals and legumes are intercropped [2, 7, 8, 28].

5.3. The Economic Payoff: More Green for Your Farm

Our strong economic analysis, showing higher profits and better Benefit-Cost Ratios (BCR) in sweet corn-vegetable legume intercropping systems, makes a compelling case for farmers to adopt these practices. The financial benefits come from a few key areas. First, simply getting more total fodder from the same land means more income. Second, the improved nutritional quality of that fodder, especially the higher protein, adds significant value. This means farmers can either sell their high-quality fodder for a better price or, even better, spend less on buying expensive protein supplements for their animals.

Third, and this is a big one, the legumes' natural ability to fix nitrogen dramatically cuts down on the need for synthetic nitrogen fertilizers. This translates into real savings on input costs, directly boosting the farmer's profit margin. And let's not forget the advantage of having multiple income streams. Farmers aren't just relying on sweet corn; they also have the marketable produce from the legumes (like green pods from field beans or cowpeas). This diversification acts as a financial buffer, making farm income more stable and resilient, especially if market prices for one crop fluctuate [5, 6, 14, 15, 16, 21, 26, 38]. The sweet corn + field bean (2:2) system, which showed the highest profitability, is a perfect example of how choosing the right intercropping combination can maximize both what you grow and what you earn. This approach fits perfectly with the idea of sustainable agriculture, which aims for farming methods that are good for the environment, financially sound, and fair to farmers [23].

5.4. How Our Findings Stack Up (Comparison with Existing Literature)

Our study's results largely confirm and build upon what a lot of other research has already shown about intercropping cereals and legumes. The increased fodder yields we observed are consistent with studies by Arif et al. [1], Ginwal et al. [6], and Javanmard et al. [13], all of whom reported more fodder when maize was intercropped with legumes. The excellent performance of cowpea and field bean as intercrops in boosting sweet corn fodder productivity also aligns with findings from Egbe et al. [4] and Hugar and Salakinkop [10].

The improvements we saw in fodder quality – more protein, less fiber – are also well-documented in other research. Ginwal et al. [7, 8] and Ram [28] similarly reported higher protein and lower NDF/ADF in maize-legume intercrops. The reasons we've suggested for these improvements, such as better nitrogen nutrition and how plants distribute their energy, are consistent with explanations from previous work.

From an economic standpoint, our findings of higher profits and better BCRs are in agreement with studies by Gargi et al. [5], Kithan and Longkumer [14, 15], Kour et al. [16], Marer et al. [21], and Vilhekar et al. [38]. The consistent profitability of various intercropping systems across different regions and crop combinations truly highlights that intercropping is a universally valuable economic strategy for farmers.

While our study's findings are generally consistent, it's natural for specific yield amounts or quality numbers to vary slightly compared to other research. This could be due to differences in local climate, soil types, the specific crop varieties used, farming practices, or even the exact intercropping ratios. Nevertheless, the overwhelmingly positive trends we observed in this research significantly add to our understanding of sustainable fodder production.

5.5. What We Didn't Cover (Limitations of the Study)

While our study offers valuable insights, it's important to acknowledge its boundaries. This experiment was conducted for just one rabi season in a specific part of Karnataka. This means our results might not be perfectly applicable to all seasons or vastly different agricultural regions without more testing. We also didn't dive deep into the long-term effects of these intercropping systems on soil health, such as how much carbon they store, how nutrients cycle over many years, or the health of soil microbes. Plus, our focus was primarily on fodder yield and quality at one specific harvest time; exploring how different harvest timings might further optimize fodder quality and animal performance could be a fruitful area for future research.

5.6. Putting It to Practice: Recommendations for Farmers

Based on our solid findings, we highly recommend that farmers in Karnataka and similar regions consider adopting sweet corn-based vegetable legume intercropping systems. Specifically, the sweet corn + field bean (2:2 row proportion) system stood out as the most compatible, productive, and financially rewarding choice. By integrating this practice, farmers can significantly boost their fodder production, improve its nutritional value for their livestock, and secure better financial returns. The added bonus of relying less on expensive synthetic nitrogen fertilizers also means lower costs and more environmentally friendly farming. This approach offers a truly sustainable path to overcome India's fodder shortage, enhance livestock productivity, and make small and marginal farming enterprises more resilient and profitable for the long run.

CONCLUSION

Our study clearly shows that sweet corn-based vegetable legume intercropping systems are a superior and more sustainable choice for fodder production in Karnataka, India. These systems dramatically increase overall fodder yield by making the most of how cereals and legumes work together. Crucially, they also significantly improve the nutritional quality of the fodder – we saw more protein and less of the tough-to-digest fiber, resulting in more nutritious feed for animals. From a financial perspective, these intercropping systems, especially sweet corn intercropped with field bean in a 2:2 row proportion, proved to be much more profitable, offering higher net returns and better Benefit-Cost Ratios compared to growing single crops. The powerful teamwork between sweet corn and legumes, particularly the legumes' ability to fix nitrogen, is at the heart of all these benefits. Adopting these intercropping practices can play a vital role in closing the fodder gap, improving livestock health, and fostering sustainable and economically thriving agriculture, ultimately strengthening the food and livelihood security of farming communities in the region.

Future Research Directions

While our study provides compelling evidence for the benefits of sweet corn-vegetable legume intercropping, there's always more to learn! Here are some exciting areas for future research to make these systems even better and ensure their long-term success:

- Long-Term Soil Health Check-up: We need multi-year studies to see how these intercropping systems impact soil health over time. This includes looking at how much organic carbon they store, how nutrients cycle, and the health of the tiny microbes living in the soil. This will give us a complete picture of their environmental benefits.
- Finding the Best Varieties: Let's explore a wider range of sweet corn hybrids and vegetable legume varieties. We should specifically look for traits that are great for fodder production, like how much biomass they produce, their nutrient content, and how well they resist diseases.
- Perfecting the Planting Pattern: We can experiment with even more planting geometries, row arrangements, and plant populations beyond what we tested. The goal is to find the most efficient setups that maximize both total biomass yield and fodder quality in different soil and climate conditions.
- Optimal Harvest Time for Quality: Researching how different harvest timings affect the quality and digestibility of intercropped sweet corn and legumes is crucial. We want to pinpoint the ideal stage to get both the most quantity and the best nutritional value for livestock.
- Water Wisdom Under Stress: Given growing concerns about water scarcity, we should study how efficiently these intercropping systems use water, especially in areas with limited irrigation or during droughts.
- Pest and Disease Detective Work: A more detailed investigation into how intercropping specifically affects the presence and severity of pests and diseases in sweet

corn and legumes. This could include looking at the role of natural predators and how plants interact chemically.

- Building Climate Resilience: We need to evaluate how well these intercropping systems can withstand future climate changes, like rising temperatures and altered rainfall patterns, and figure out how to make them even more resilient.
- Farming with Farmers (Participatory Research): It's essential to involve farmers directly in future research. This will help us understand how practical these systems are, how easily they can be scaled up, and if they truly fit into the social and economic lives of farming communities, encouraging wider adoption.

By exploring these areas, we can continue to refine and improve our understanding and implementation of sweet corn-vegetable legume intercropping systems, making a significant contribution to sustainable agriculture and ensuring fodder security for our livestock.

REFERENCES

Arif, M., Kumar, A., Pourouchottamane, R., Gupta, D. L., Singh, M. K., & Rai, B. (2022). Effect of intercropping row ratios on yield and nutritive value of maize and cowpea fodder. Range Management and Agroforestry, 43(2), 292–298.

Carmi, A., Aharoni, Y., Edelstein, M., Umiel, N., Hagiladi, A., Yosef, E., Nikbachat, M., Zenou, A., & Miron, J. (2006). Effects of irrigation and plant density on yield, composition and in vitro digestibility of a new forage sorghum variety, Tal at two maturity stages. Animal Feed Science and Technology, 131, 120–132.

Dahmardeh, M., Ghanbari, A., Syasar, B., & Ramroudi, M. (2010). The role of intercropping maize (Zea mays L.) and cowpea (Vigna unguiculata L.) on yield and soil chemical properties. African Journal of Agricultural Research, 5, 631–636.

Egbe, O. M., Alibo, S. E., & Nwueze, I. (2010). Evaluation of some extra-early maturity cowpea varieties for intercropping with maize in Southern Guinea Savanna of Nigeria. Agriculture and Biology Journal of North America, 1, 845–858.

Gargi, R., Shukla, D., Kumar, R., & Pandey, R. K. (1997). Inter-cropping for profitable sericulture in Purvanchal. Indian Silk, 34, 31–33.

Ginwal, D. S., Kumar, R., Ram, H., Dutta, S., Arjun, M., & Hindoriya, P. S. (2019a). Fodder productivity and profitability of different maize and legume intercropping systems. Indian Journal of Agricultural Sciences, 89(9), 1451–1455.

Ginwal, D. S., Kumar, R., Ram, H., Dutta, S., Arjun, M., & Hindoriya, P. S. (2019b). Quality characteristics and nutrient yields of maize and legume forages under changing intercropping row ratios. Indian Journal of Agricultural Sciences, 89(3), 281–286.

Ginwal, D. S., Kumar, R., Ram, H., Meena, R. K., & Kumar, U. (2019). Quality characteristics and nutrient yields of maize and legume forages under changing intercropping row ratios. Indian Journal of Agricultural Sciences, 89(3), 281–286.

Gomez, K. A., & Gomez, A. A. (1984). Statistical procedures for agricultural research (2nd ed.). John Wiley.

Hugar, A., & Salakinkop, S. R. (2022). Evaluation of sweet corn (Zea mays convar. saccharata L.) based intercropping system with vegetable legumes during winter season. Journal of Farm Sciences, 35(1), 85–89.

Jackson, M. L. (1973). Soil chemical analysis. Prentice Hall of India Pvt. Ltd.

Jan, R., Saxena, A., Jan, R., Khanday, M. U. D., & Jan, R. (2016). Intercropping indices and yield attributes of maize and black cowpea under various planting patterns. The Bioscan, 11(2), 1–5.

Javanmard, A., Nasab, A. D. M., Javanshir, A., Moghaddam, M., & Janmohammadi, H. (2009). Forage yield and quality in intercropping of maize with different legumes as double cropped. Journal of Agriculture, Food and Environment, 7(1), 163–166.

Kithan, L., & Longkumer, T. (2017a). Economics of maize (Zea mays L.) and soybean (Glycine max (L.) Merrill) intercropping. International Journal of Bio-resource and Stress Management, 8(3), 401–404.

Kithan, L., & Longkumer, T. (2017b). Production potential of maize (Zea mays L.) based intercropping systems under foothill condition of Nagaland. International Journal of Bio-resource and Stress Management, 8(5), 628–634.

Kour, M., Thakur, N. P., Kumar, P., & Charak, A. S. (2016). Productivity and profitability of maize (Zea mays) as influenced by intercropping of rajmah (Phaseolus vulgaris) and nutrient management techniques under sub-alpine conditions of Jammu. Legume Research, 39(6), 970–975.

Lai, H., Gao, F., Su, H., Zheng, P., Li, Y., & Yao, H. (2022). Nitrogen distribution and soil microbial community characteristics in a legume–cereal intercropping system: A review. Agronomy, 12(8), 1900.

Manasa, P., Maitra, S., & Barman, S. (2018). Effect of summer maize–legume intercropping system on growth, productivity and competitive ability of crops. International Journal of Management Technology and Engineering, 8(12), 2871–2875.

Manasa, P., Maitra, S., & Barman, S. (2020). Yield attributes, yield and competitive ability and economics of summer maize–legume intercropping system. International Journal of Agriculture, Environment and Biotechnology, 13(1), 33–38.

Manpreet, K., Thakur, N. P., Kumar, P., & Charak, A. S.

(2016). Productivity and profitability of maize (Zea mays L.) as influenced by intercropping of rajmash (Phaseolus vulgaris) and nutrient management techniques under sub-alpine conditions of Jammu. Indian Journal of Legume Research, 39(6), 970–975.

Marer, S. B., Lingrajju, B. S., & Shashidhra, G. B. (2007). Productivity and economics of maize and pigeonpea intercropping under rainfed condition in northern transitional zone of Karnataka. Karnataka Journal of Agricultural Science, 20(1), 1–3.

Montgomery, E. G. (1911). Correlation studies in corn. Nebraska Agricultural Experiment Station Annual Report, 24, 108–159.

Muhie, S. H. (2022). Novel approaches and practices to sustainable agriculture. Journal of Agriculture and Food Research, 10, 100451.

Nair, M. R., Sejian, V., Silpa, M. V., Fonsêca, V. F. C., de Melo Costa, C. C., Devaraj, C., ... & Bhatta, R. (2021). Goat as the ideal climate-resilient animal model in tropical environment: Revisiting advantages over other livestock species. International Journal of Biometeorology, 65, 2229–2240.

Panda, S. K., Maitra, S., Panda, P., Shankar, T., Pal, A., Sairam, M., & Praharaj, S. (2021). Productivity and competitive ability of rabi maize and legume intercropping system. Crop Research, 56(3–4), 98–104.

Pandey, A. K., Prakash, V., Singh, R. D., & Mani, V. P. (1999). Effect of intercropping pattern of maize and soybean on yield and economic under mid hills of N-W Himalayas. Annals of Agricultural Research, 20(3), 354–359.

Parimaladevi, C., Ramanathan, S. P., Kumar, S. N., & Suresh, S. (2019). Evaluation of maize-based intercropping systems in Thamirabarani basin of Tamil Nadu. Journal of Pharmacognosy and Phytochemistry, 8(3), 4051–4056.

Ram, S. N. (2008). Productivity and quality of pasture as influenced by planting pattern and harvest intervals under semiarid conditions. Indian Journal of Agricultural Science, 42(2), 38–41.

Ramanakumar, K., & Bhanumurthy, V. B. (2001). Effect of staggered sowing and relative proportion of cowpea on the performance of maize + cowpea. Forage Research, 27(2), 105–110.

Saban, Y., Mehmt, A., & Mustafa, E. (2007). Identification of advantages of maize–legume intercropping over solitary cropping through competition indices in the East Mediterranean region. Turkish Journal of Agriculture and Forestry, 32, 111–119.

Sadasivam, S., & Manickam, A. (1992). Biochemical methods for agricultural sciences. Wiley Eastern Ltd.

Shankar, M. A., & Devaiah, M. C. (2002). Intercropping in rainfed mulberry (PhD thesis). University of Agricultural Sciences, Bangalore, pp. 69–71.

Shridhara, H. S., Salakinkop, S. R., & Harlapur, S. I. (2019). Effect of leguminous intercrops on maize productivity and economics. Journal of Farm Science, 32(4), 190–193.

Singh, D. N., Bohra, J. S., Tyagi, V., Singh, V., & Gaurendra, T. R. B. (2022). A review of India's fodder production status and opportunities. Grass and Forage Science, 77(1), 1–10.

Singh, G., & Singh, O. P. (1993). Intercropping compatibility of different crops with winter maize. Indian Journal of Agronomy, 38(4), 519–522.

Van Soest, P. J. (1963). Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. Journal of the Association of Official Analytical Chemists, 46, 829.

Venkatesh, S., Sanjay, R., & Shekhar, J. C. (2003). Sweet corn (Speciality corn technical series 1). Directorate of Maize Research.

Vilhekar, S. C., Badole, K. K., & Ghanbahadur, M. R. (2014). Yield and economics of sweet corn-based cropping systems in rainfed condition. Annals of Plant and Soil Research, 16(4), 316–318.

Wakchaure, M., Patle, B. K., & Mahindrakar, A. K. (2023). Application of AI techniques and robotics in agriculture: A review. Artificial Intelligence in the Life Sciences, 3, 100057.