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# Legume-cereal combination approach for quality of forage production and sustainability: A review

**Sourabh Kumar, Magan Singh, RK Meena, Rakesh Kumar, Hardev Ram, Sanjeev Kumar and VK Meena**

**Sourabh Kumar**
Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**Magan Singh**
Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**RK Meena**
Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**Rakesh Kumar**
Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**Hardev Ram**
Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**Sanjeev Kumar**
Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**VK Meena**
Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**Corresponding Author:**
**Magan Singh**
Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**Abstract**
Agriculture and allied activities are the mainstays for the Indian population. Farmers usually prefer growing food and commercial crops rather than fodder crops. This also creates a deficiency for the availability of quality fodder within the country, as fodder production constitutes only 4% of the total cultivated area. Intensive use of agricultural chemicals to grow food grains has already affected the environment of soil health and climate change. Legume fodder crops are very efficient in buffering these negative impacts on the environment and increasing animal production. Therefore, involving scientific methods like combining legume fodder with cereal will provide high-quality fodder and increase the soil organic matter, which generates better soil nutrient status and better crops, improving water conservation and reducing soil erosion.

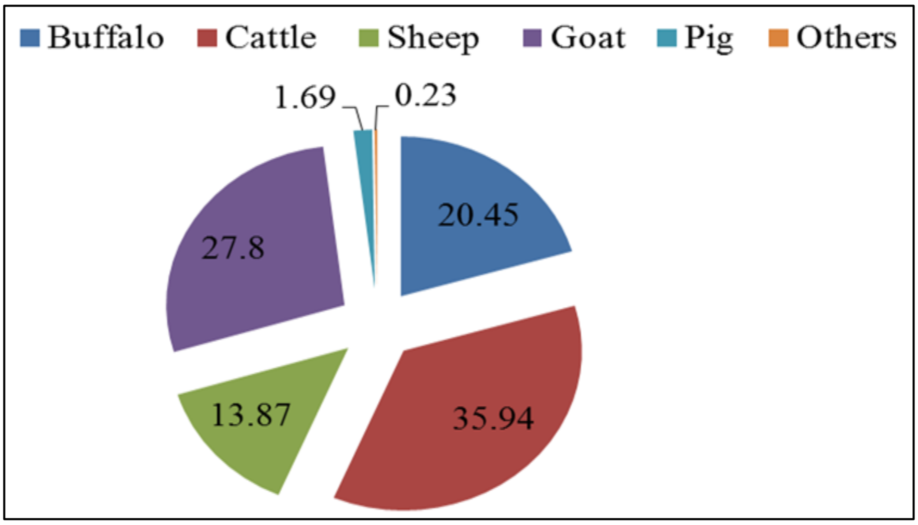
**Keywords:** Fodder crops, fodder quality, intercropping and soil fertility

## Introduction

Agricultural sector is classified as the mainstay for different parts of the world for providing food and energy (Jones and Ejeta, 2016) [47]. Asia, Africa and South-west Asia has majority of their population employed in this sector. This is because more than half of the population of countries like India is engaged in agriculture and its allied sectors which contribute 13.7% of the GDP of the country; therefore, they are considered the backbone of these developing economies (Vision, 2050) [110]. Crop production and animal husbandry are culturally, religiously, and economically intertwined with the intricate fabric of society in many emerging countries like India where mixed farming and livestock rearing are intrinsic aspects of rural life as it produces 50% world`s cereals and staples for poor people consumption (Letty and Alcock, 2013) [55]. When agriculture fails to increase farmer`s income and development, livestock helps them withstand in such demanding conditions. Livestock contributes nearly 5-6% to the GDP annually and employs about 2.8 billion people in the Asian countries. It also generates a wide range of products that enables the farmers to diversify their income sources and reduce risk. Therefore, livestock sector helps provide nutrition to both humans as well as crops (Sugiyama, *et al.* 2003) [102]. Power for agricultural operations and rural transportation makes it a precious asset for small and marginal farmers of world, which can be easily liquefied during emergencies. The need for livestock products like milk and meat in the last 20 years had been doubled in developing countries and will rise at an annual rate of 2.7% and 3.2%, respectively (Delgado *et al.*, 1999) [27]. The demand for these products will further increase in the future by 80%. So, we cannot ignore the role of the livestock sector in Asian and developing countries because most of the farmers are small and marginal ones, and this sector contributes about 21% of their family income (Sharma *et al.*, 2009) [89].

India has only 2% of the total geographical area whereas its inhabitants 15% of the livestock population of the world, i.e., 190.90 million heads of cattle and 108.70 million buffaloes, followed by other species, gives a total livestock population of 535.78 million (20$^{th}$ livestock census, 2013; Figure1). This supports the fact that animal products produced from livestock population of Asian regions in comparison to the world`s share is quite low.

The economic viability of livestock population is primarily determined by the animal's genetic potential for production, good health care, a balanced diet, and effective marketing of the harvested goods. In contrast, genetic development and health maintenance are prerequisites for sustainability, efficient feeding, and marketing. It will assist farmers in raising their productivity and profitability, which is directly dependent on feed and fodder supplies, as feeding accounts for 65-70 percent of the overall cost of livestock farming (Nolan and Toure-Fall, 2003) [68]. However, Most of the developing countries cannot provide sufficient feed and fodder to its livestock resources because forages offered to these animals are mostly poor in quality. In India, Fodder crops are grown in only 4% area of the total cultivated area, which also leads to scarcity of green fodder, dry crop residues, and concentrate feeds, i.e., 35.6%, 10.95 %, and 44 %, respectively (Vision 2050, IGFRI) [110]. Also, there will be no scope for further increase in the land area as per the current growth rate scenario of the human population of the world. Growing quality fodder to feed the livestock is not the only problem, but increased environmental pollution and decreasing soil fertility are major challenges for the world economies. This is because mono-cropping and conventional farming caused severe threat to the world`s environment due to the high cost and burning of fossil fuels with excessive natural resources. So, in order to decrease the gap between the demand of quality feed and fodder in developing countries like India and for addressing environmental pollution of the world, strategies are required to include techniques that improve the availability of better-quality fodder and its production along with environmental sustainability. Growing forage legumes in combination with cereal crops to boost the feeding value of crops and residues is another approach that has shown promise for farmers with limited resources to feed their animals better while contributing to soil fertility which in turn leads to a reduction in environmental pollution caused by various types of agrochemicals (Mengistu, 2002; Bekunda *et al.*, 2010) [118, 119]. However, on the other hand, farmers are more inclined to adopt this technology of planting forage legumes alongside cereal crops if it increases fodder supply while not lowering grain yields. This paper will discuss the impact of legume cereal combinations on growth aspects of fodder crops, soil nutrition, and other additional advantages.




(Chauhan and Arti, 2020) [120]

**Fig 1:** Percent Contribution of different species in total livestock population

Combining legumes and cereal in the cropping system is an example of sustainable agriculture which in turn leads to increasing diversity in the agricultural system. This is an ancient practice that is more common among small holding farmers of developing economies like India. Combining legume and cereal fodder crops has a better perspective for farmers in developing countries especially India. It offers various advantages which includes its flexibility, profit maximization, and risk minimization ability. Furthermore, they can give a higher yield than the sole crops, yield stability, and efficient use of nutrients (Serena & Brintha, 2010) [90]. Similarly, better weed control, improvement of quality is other benefits added to this. Also, cereal crops give almost the exact yield in a combined system compared to the sole cropping system (Ijoyah, 2012) [45]. Integrating cereals and legumes has several advantages; including improving fodder quality by combining two or more crops cultivated simultaneously on the same piece of land. Enhancement of protein content has been recognized as one of the benefits of this combination in forage production (Herbert *et al.*, 1984) [39]. Incorporating legumes into a cereal-based farming system could help to maintain soil health, crop, and livestock output (Caballero and Goicoechea, 1995) [23]. Legume-cereal combinations are often used as a management strategy for increasing fodder quality and quantity. The best approach in integration is to select the suitable component crops in correct proportions to utilize the different benefits of available resources. According to Ofori and Stern (1987) [69], intercropping is growing more than one crop species simultaneously in the same field during a growing season. Willey (1979a) [112] stresses the significance of intercrop competition, whereas Andrews and Kassam (1976) [7] categorize intercropping into four principal types – Mixed cropping, Row intercropping, Relay intercropping, Strip intercropping (Figure 2).

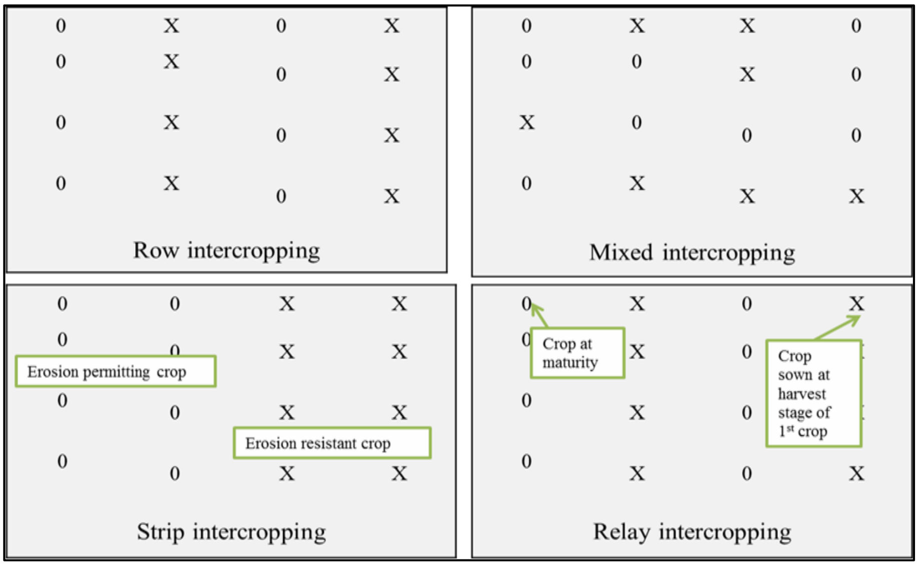



**Fig 2:** Layout of different types of intercropping with 0 and X as crops A and B

There is intercrop competition during all or part of crop growth in intercropping. i.e, crop intensification in the same space and time (Crusciol *et al.* 2011 [22]; Biabani *et al.* 2008) [15]. Intercropping was mainly adopted as insurance against crop failure in rainfed conditions as rainfed agriculture constitutes a major portion in Asian region. However, the core objective of intercropping is higher productivity per unit area in addition to immovability in production (Ahmad *et al.* 2006 [2]; Mucheru-Muna *et al.* 2010) [60]. Intercropping is critical for developing sustainable food and fodder production systems with low external inputs (Adesogan *et al.*, 2002) [6]. This is because it has potential benefits like improved productivity and profitability (Yildirim and Guvence, 2005) [116], enhancement of soil fertility through the addition of nitrogen by fixation and excretion from the component legume (Hauggaard-Nielsen *et al.*, 2001) [40], proficient use of resources (Knudsen *et al.*, 2004) [48], reducing loss caused by pests, diseases, and weeds (Banik *et al.*, 2006 [16]; Sekamatte *et al.*, 2003) [97], and upgrading the quality of fodder through the complementary effects of two or more crops grown simultaneously on the same part of the land (Bingol *et al.*, 2007 [18]; Lithourgidis *et al.*, 2007 [52]; Ross *et al.*, 2004) [82]. Thus, we will discuss the effects of intercropping on the growth and development of component fodder crops, forage quality, and their role in enhancing soil fertility.

## 1. Effect of intercropping on component fodder crops

In order to achieve all the benefits of intercropping, the choice of component crops is the most crucial step along with their spatial arrangement. This is because it would be helpful in the proper utilization of resources by the component crops, which leads to higher biomass production (Gare *et al.*, 2009 [35]; Okogun and Mulongoy, 1999) [71]. According to Eskandari *et al.* (2009) [30], this decision can be made easier if component fodder crops are selected based on the following criteria:

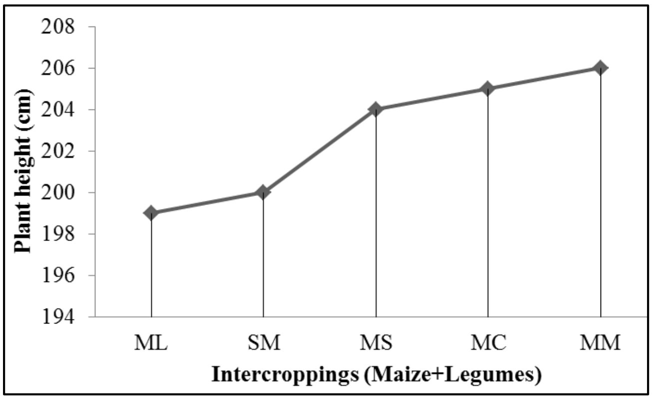
- The fodder crop species should have high protein content.
- They should be able to complement each other in growth and development with no antagonistic interaction.
- They should exhibit contrasting morphological and physiological characteristics, and there should be specific temporal variances between their growth stages which could lead to better utilization of resources by the fodder crops.
- They should be able to yield maximum harvest at the same time.
- They should have the same sowing date as much as possible.

In an intercropping system, the competition for natural resources like soil, water, light, and nutrients is higher in cereals than in legumes (Thobatsi, 2009) [106]. when the component crops have different maturity times, the peak time for the demand of light, water, and nutrients will be different, which is best for an intercropping system (Seran and Jeyakumaran, 2009) [98]. This can be understood with an example, i.e., when green gram is intercropped with maize, then green gram matures at 60 days after sowing, which is suited for maize (Rana and Rana, 2011) [84]. The plant population of component crops is maintained less than the sole crop in an intercropping system. This is because yield could not be predicted under the average plant density of component crops (Seran and Barimtha, 2010) [90]. In bean–maize, intercropping under average plant density can decrease the dry matter of maize and each bean plant separately (Morgado and Willey, 2003) [62]. A similar trend was observed when soybean yield decreases by 21 and 23 % by enhancing the maize plant population at 44,440 and 53,330 plants/ha, successively (Muoneke *et al.* 2007) [63]. An increase in maize plant population increases its dry matter, but it decreases light interception to other component crops (Prasad and Brook, 2005) [74]. The sowing time of each crop is the most crucial factor which decides the increase or decrease in the yield of an intercropping system. Growing maize with cowpea instantaneously in an intercropping system provides efficient production, and sowing them simultaneously increases the yield per unit area (Mongi *et al.*, 1976) [64]. Lusembo *et al.* (1994) [56] reported that seed yield of Centro was found to be affected due to different time of planting in case of centro-cassava intercropping.

The spatial arrangement of component crops is another critical aspect in intercropping because of its impact on component crop compatibility (Mutungamiri *et al.* 2001 [61]; Oseni and Aliyu 2010 [70]; Iqbal *et al.* 2018d) [46].When the legume intercrop's row proportion was increased in intercropping, agro-qualitative aspects of the mixed forage were improved, but overall biomass output was reduced (Surve *et al.* 2011) [101]. When sorghum-cowpea and sorghum-cluster bean were intercropped in a 2:1 row ratio, the fresh and dry biomass was higher than in other spatial arrangements (Iqbal 2018) [46]. However, adjustments can be made in the position of fodder crops in spatial arrangements for intercepting more light and high dry matter production, but it may be difficult sometimes as plants preferred in a mixture are not always ones with the greatest leaves for intercepting sun energy (Francis, 1989) [34]. Therefore according to Willey (1979b) [113], because the higher gain in light use is anticipated to be obtained over time, 'temporal complementarity' is likely to generate more benefits than spatial complementarity.' This is especially true in forage production, where crop combinations can be manipulated to assure ground cover in the latter part of the growing season, maximizing resource utilization. Pereira *et al.* (2017) [73] reported that increase in competition for growth resources such as light in case of legume –cereal intercropping leads to decrease in growth and forage quality of component crops. Hence, the above evidence suggests a need to find correct component crops for better utilization of temporal and spatial resource under different crop combinations suited for different climatic regimes of Asia especially indo-gangetic-plains which produces significant agriculture production for Asian region and supports a major share of world population.

## 2. Effect of intercropping on growth parameters

Over the years, research studies have shown that different growth parameters like plant height, number of leaves, number of branches, stem girth of component crops are affected in an intercropping system. Plant height has increased in the case of maize in maize-cowpea in the intercropping system (Rathor, 2015) [86]. A similar effect was found when maize intercropped with cowpea resulted in an increase in plant height (234.73), number of leaves per plant (1.08), number of rows per ear (15.30), number of grains per row (41.30), grains weight per ear (148.19) and 100-grain weight (33.34) in case of maize (Hamd Allah *et al.*, 2014) [42]. Intercropping studies have also shown that when cereal like maize has grown with different leguminous plants like cowpea, guar, and clitoria, legumes have significantly affected the plant height of maize (Ahmed *et al.*, 2019) [2]. When maize intercropped with cowpea under varying nitrogen treatments, then plant height, stem diameter, leaves per plant, LAI (leaf area index) of both maize and cowpea showed the maximum value (Tamta *et al.*, 2019 [105]; Kumar *et al.* 2014 [49]; Sharma *et al.* 2016) [37]. It is reported that when cereals crops like maize, sorghum, pearl millet are taken in an intercropping with cowpea and horse-gram, then plant height, leaf number, and leaf: stem ratio, crop growth rate, and relative growth rate were not influenced (Gangaiah, 2004) [36]. Rana *et al.* (2001) [85] reported that maize intercropped with legumes had shown a significant increase in plant height than pure maize. Birteeb *et al.* (2011)[19] reported that when maize intercropped with legumes, i.e., Maize + Centrosema pubescent (MC), Maize + Lablab purpureus (ML), Maize + Stylosanthes guianensis (MS), Maize + Macroptiliumthyroids (MM) and compared with Sole maize then no significant effect was observed, but plant height of maize was more in intercropped plots than Sole maize(SM) except Maize + Lablab Purpurea (Figure 3). Therefore, research should be directed toward finding new crop combinations for enhancing more agronomic growth of component crops under diversified climatic conditions under tropical conditions like India.




(Birteeb *et al.* (2011) [121]

**Fig 3:** Plant height of maize intercropped with different legumes

## 3. Effect on yield and yield attributes in intercropping

A significant economic product in fodder crops is the whole plant used for animal feeding purposes. Therefore, biomass produced per unit area is the primary concern in the case of fodder crops. All agronomic interventions and technologies involved in the case of fodder crops will be aimed to boost the green fodder yield and dry fodder yield. El-Said and Sharief (1993) [31] reported that be seem grown with ryegrass in mixed cropping yielded higher yields than their sole crops. Berry *et al.* (2002) [14] informed that organic manures, when utilized as a source of nutrients in legume –grass mixture, resulted in a significant increase in fodder production in different cuts. Abraham and Lal (2002) [1] also reported that using different forms of nutrients in combination significantly influenced yield and dry matter production. Meena and Mann (2006) [59] stated that collective use of inorganic + bio fertilizers had given maximum green fodder (65.45 t/ha), dry matter yield (16.98 t/ha) in berseem. Bali *et al.* [12] use of 100 percent NPK with 10 t FYM/ha to the rice-berseem system to rice-berseem system magnified the grain and straw yield of rice as well as green fodder yield of succeeding berseem at Shalimar, Srinagar, and Jammu & Kashmir. Bow *et al.* (2008) [20] reported that the sole crop of legume fodder stands produced better yields than the sole crop of grasses. Yolcu *et al.* (2011) [117] also conveyed that when legumes are mixed with grass, then fodder production yielded highest in the first cut when organic sources of fertilizers are used. Duhan (2013) [29] reported that the fodder production of sorghum was increased from 41.11 to 56.97 q/ha when 100 percent of the recommended nitrogen dose was applied by FYM. Rasool *et al.* (2015) [83] reported 75% NPK RD (inorganic) +FYM (4.5 t/ha) + bio fertilizers (Azotobacter + Phosphate solubilizing bacteria (PSB) proved to be better than other treatment combinations in producing more cob yield with and without husk, fodder yield, and green biomass yield. Arya and Niranjan (1994) [8] reported that when sorghum grown mixed with cowpea with the mutual application of organic and inorganic nutrients, then this system gave high green fodder yield than chemical fertilizers alone. Sweet sorghum + field bean intercropping system at 2:1 row proportion yielded significantly higher mixed green forage (59.5 t/ha), dry matter (11.35 t/ha), crude protein (812 kg/ha), crude fiber (3820 kg/ha.), ether extract (259 kg/ha) and total ash (804 kg/ha) trailed by sorghum + cowpea intercropping system at 2: 1 row proportion and sweet sorghum + horse gram (2: 1) ratio (Thippeswamy and Alagundagi, 2001) [107]. In nitrogen transfer from lima bean to sorghum through roots intermingling, mixed intercropping was found to be more effective than row intercropping systems, resulting in higher mixed forage yields (Reza *et al.*, 2012) [87].Evidences suggest that fodder legumes suffer more losses in yield than cereals in monoculture; therefore, legume-cereal intercropping will enhance the quantity of fodder production, thereby decreasing the fodder deficiency gap within the tropical and sub-tropical parts of world (Patel and Rajagopal, 2001 [72]; Ayub and Shoaib, 2009) [10]. Amole *et al.* (2014) [3] reported that cereal fodder like maize intercropped with legumes like tephrosia, Lablab and macuna then maize + tephrosia resulted in higher dry matter production. Intercropping is mainly practiced for higher fodder production in temperate regions and needs to be practiced more in tropical regions of the world for the same purpose (Anil *et al.*, 1998[4]; Lithourgidis *et al.*, 2006) [52]

## 4. Effect on other characteristics features of intercropping

One of the main reasons intercropping is more prevalent in developing countries like India and different parts of the world are that it is a more stable cropping system than monocropping (Horwith, 1985) [43]. This may be attributed to the astonishing fact that intercropping helps in the partial restoration of diversity that is lost under monocropping. In case of intercropping of grass legume mixture, higher light penetration will also result in increase in nitrogen response and higher dry matter production (Van den Berg & Kruger, 1990) [111]. From this perspective, intercropping provides high insurance against crop failure, especially in areas prone to extreme weather conditions such as frost, drought, and flooding, and overall provides greater financial stability for farmers, making the system particularly suitable for labor-intensive small farms (Eskandari *et al.*, 2009) [30]. Combining legume and cereal fodder helps control soil erosion in areas prone to soil erosion in hilly areas and reduces runoff by 20-30% compared to cereal component and 45-50% in comparison to legume component (Leihner *et al.*, 1996 [51]; Zougmore *et al.*, 2000) [119]. For some crops that are prone to lodging, intercropping can help in improving lodging resistance (Assefa and Ledin, 2001) [9]. Legumes like pea are more prone to lodging with thinner stemsdue to shading effects. Therefore, cereal components like oat will provide support to pea and act as a wind barrier for pea, reducing lodging (Rauber *et al.*, 2001) [89]. When cereal legumes like pea, faba bean, and lupin were grown mixed with barley, disease incidence was reduced by 20–40% compared to their sole crops (Hauggaard-Nielsen *et al.*, 2008) [41]. Yan *et al.* 2013 reported that utilizing growth retardant like unicozole in intercropping system like relay strip cropping raise $NO_3$-N, $NH_4^+$-N, and total amino acid content inside xylem sap, increasing the potential for leaf and root N reduction and assimilation, as well as increasing leaf and root N content. Bhakar *et al.* (2019) [17] reported that intercropping of legume and cereal resulted higher benefit: cost (B: C ratio) than monocropping under tropical conditions. Besides higher and quality fodder production, intercropping also provide several advantages over any other cropping system.

## 5. Effect on forage quality in intercropping

The quality of the produced fodder assumes uttermost importance for the livestock industry. Many efforts are given to maintain the fodder quality within a reasonable limit and free it from the anti-quality constituent. Different types of anti-quality constituents develop in fodder crops due to their ineffective management at the agronomic and management level (Table: 1).

**Table 1:** Antinutritional factor in forage crops

| Sl.no | Anti-quality Constituents | Fodder crops | Plant part synthesized/ contained |
|---|---|---|---|
| 1 | HCN/Dhurin/Prussic acid | Sorghum | Roots, Young plants |
| 2 | Saponins | Alfalfa/Lucerne, berseem | Leaves, Stems |
| 3 | Oxalic Acid | Paddy straw, Guinea Grass, Bajra and Hybrid Napier, Setaria Grass, Kikyu & Buffelgrass | Leaf, Stem and Young plants |
| 4 | Coumarins | Sweet Clover (Melilotus Sp.) | Leaves |
| 5 | Mimosine | *Leucaena leucocephala* (subabul) | Leaves and Stems |
| 6 | β-N-oxalyl-L-α,β-diamino propionic acid (β-ODAP or BOAA) | Lathyrus/ Khesari | Leaves and seed |
| 7 | Tripsin Inhibitors | Cowpea | Leaves and stems |
| 8 | Cyanogenic glycosides | Sudan grass, White Clover, Sorghum | Leaves |
| 9 | Nitrate | Sudan grass, Pearl millet, Oats | Leaves and Stems |
| 10 | Tannins | Fodder tree/Shrubs | Leaves, Seed Coat |
| 11 | Glucosinolates (Goitrogens) | Cabbage, Turnips, Rapeseed and Mustard green | Root, Stem, Leaves, and Seed |

(Modified from Ramteke *et al.* 2019)

Over the years, studies around the globe support the fact that the fodder quality of different crops is more affected in the intercropping system than sole cropping. El-Said and Sharief (1993) [31] reported that berseem grown with ryegrass in mixed cropping had superior fodder quality than their sole crops. Wiersma *et al.* (1999) [114] reported that berseem mixed with ryegrass might be used as annual mixtures and also important in order to provide balanced nutrition to animals. Muir (2002) [65] again reported that when berseem mixed with ryegrass using organic sources of nutrients, it enhanced the crude protein content in fodder crops. Meena and Mann (2006) [59] also reported that integrated application of different sources of nutrients like 20 kg N + 60 kg P along with the mixture of bio fertilizers like *Rhizobium trifolii* and phosphate solubilizing bacteria (PSB) had increased the crude protein content by 19.7% in case of berseem fodder. Puri and Tiwana (2008) [75] at Ludhiana reported that 25t FYM/ha combined with 100 kg N/ha produced palatable and nutritious fodder in large quantities in the case of maize fodder crop. Singh *et al.* (2015) [99] reported that fodder quality parameters like juice percentage (26.2), dry matter content (25.6%), digestibility (48.7%), and neutral detergent fibre content (61%) were increased with application @ 75% N through inorganic sources and remaining 25% through FYM. Smith (1987) [100] commented that when ryegrass was grown mixed with legumes, it enhanced the quality of fodder produced with higher dry matter yield, crude protein content, and yield if harvested in 2-month intervals without any fertilizer application. Similar results found by mixing ryegrass with common vetch as crude protein (CP) and PDIN (protein digested in the small intestine when rumen nitrogen is less) were found to be higher than the pure stand of ryegrass (Rahetlah *et al.*, 2013) [80]. Intercropping of grasses like ryegrass with legumes had also enhanced the total nutritional quality of diet, which may be attributed to the legume effect, biological nitrogen fixation by Rhizobium species which also help in cost reduction due to less application of nitrogenous fertilizers (Paris *et al.*, 2012 [76]: Carvalho and Pires, 2008) [24]. Sood and Sharma (1993) [94] reported that when fodder crops like sorghum mixed with cowpea or soybean had given high-quality fodder due to high crude content of 12.8% compared to the sole sorghum 7.10%**.** Similarly, Maize intercropped with legumes like tephrosia had given improved crude protein content under tropical climate (Amole *et al.* 2014) [3]. Liu *et al.* (2006) found that the crude protein content of maize plants increased by 30.8% and 99.4% in intercropping compared with monocropping maize plants. Lauriault *et al.* (2004) [50] reported that intercropping pea with cereal fodder decreased the NDF content, reflecting higher feed intake by animals. Dahmardeh *et al.* (2009) [25] reported that intercropping of maize with cowpea had decreased the ADF content (up to 25%) by increasing the seed proportion as compared to that of monocropped plants. Anil *et al.* (2000) [4] reported that when maize and runner bean were intercropped, the ash content of maize was found to be decreased. Mason and Pritchard (1987) stated that mineral absorption percent was found to be more due to complementary effects between components of maize-soya bean intercropping. Dahmardeh *et al.* (2009) [25] reported that with maize-cowpea intercropping, the crude protein content of fodder was higher in the milky stage and lower in the doughty stage of the maize growth period. Bingol *et al.* (2007) [18] reported that some intercropping, like mixing vetch with barley, had significantly increased the yield and digestible dry matter. When barley was intercropped with common vetch, the forage quality improved, and the protein production of the barley rose without lowering the dry matter yield. (Thompson *et al.*, 1992) [108]. Intercropping legumes play a better role in increasing fertilizer use efficiency and fixing atmospheric nitrogen for utilization by its partner fodder crop. This is the primary reason for the enhancement of fodder quality in intercropping than sole cropping (Sharma *et al.*, 2000) [92]. Hence, Intercropping should be more preferred in different parts of the Asia for quality fodder production.

## 6. Effect on soil nutrition in intercropping

Soil is one of the essential natural resources for agriculture production. The present scenario of India states that excessive use of monocropping with high doses of fertilizers over the years has degraded the soil quality, thereby affecting agriculture production. Possible options should be explored quickly in order to enhance the soil quality. Intercropping has shown significant effect on soil physic-chemical properties like soil pH, bulk density and total porosity than monoculture system (Lu *et al.* 2019 [54]; Swain *et al.* 2012) [104]. Moreover, intercropping of forage crops have improved soil health and yield quality in soil with low organic carbon and lesser ability to supply nutrients to crops (Batista De *et al.* 2020) [13]. Forage crops (legumes and cereals) are much more efficient in improving soil fertility than food crops because they can sequester more soil carbon (Sundaram *et al.*, 2012) [103] (Figure 4).

Fujita *et al.* (1992) [33] reported that legumes improve the soil by fixing the environmental nitrogen transforming it from inorganic forms to ones accessible by plants for uptake. When nitrogen in the soil is not available in sufficient amount for the plants, then biological nitrogen fixation is the main mode of stay for plants at that time. Also, excessive use of inorganic chemicals for crop growth had already damaged the environment, and the introduction of legumes into the cropping system can be regarded as an alternative and sustainable way of introducing N into lower input agro-ecosystems (Fustec *et al.*, 2010) [32]. Inoculating rhizobia with phosphorous and potassic fertilizers in legume-cereal intercropping will improve harvest index and biological yield of legume component which in turn impro ves the growth characteristics of cereal component (Nyoki and Ndakidemi, 2018) [68]. Various microbial strains are responsible for fixing the nitrogen symbiotically among the different fodder crops (Table 2).

**Table 2:** Rhizobium strains for different fodder crops.

| Sl. No | Rhizobium strains | Fodder crops |
|---|---|---|
| 1 | Rhizobium japonicum | Soyabean, Cowpea |
| 2 | Rhizobium Leguminosorum | Fodder Pea, Vetch |
| 3 | Rhizobiummeliloti | Alfalfa, Medicago, Melilotus |
| 4 | Rhizobiumtrifoli | Berseem, Sweet Clover, Fenugreek |

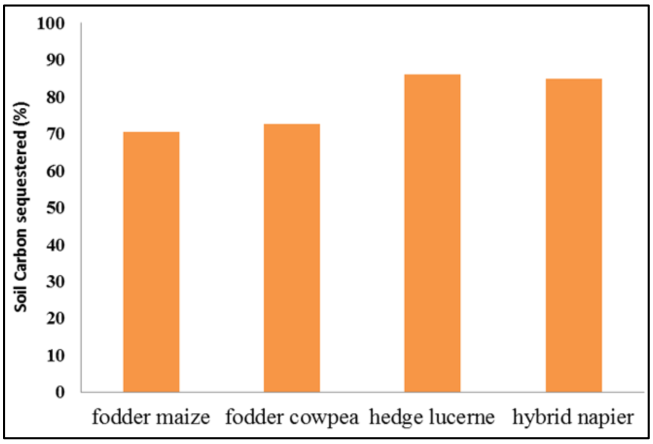



**Fig 4:** Soil carbon sequestered by the forage crops

**Nitrogen fixation on plant level is regulated in various ways (Soussana and Tallec, 2010) [95]**

1. Infectiveness (the capacity of the rhizobial strains to establish symbiosis).
2. Effectiveness (the capacity of the rhizobial strains to fix nitrogen in combination with the plant genotype).
3. Regulation of nitrogenase activity by the plant.

Regulation of nitrogen fixation in plants is believed to be a combination of these processes (Schulze, 2004) [93]. Lunnan (1989) [53] stated that the decomposition of green parts and roots of legumes also improve the soil fertility as nitrogen had been available to the succeeding crops, particularly in areas where soil fertility is low. Adu-Gyamfi *et al.* (2007) [11] reported that incorporating legumes into a cropping system provides more significant nitrogen to the cereal component as well as some residual nitrogen to the crops that follow. The interaction of legume and cereal below and above ground in an intercropping system is complex (Figure 2). This is because agricultural leftovers are the major tool for nutrient conservation through their return and decomposition. (Rahman *et al.*, 2009) [88]. Soil microorganisms are the most active components of the soil ecosystem; they play crucial roles in nutrient cycling and soil structure preservation, and their diversity is a sensitive indicator that can reflect changes in soil quality and is directly linked to plant productivity(Doran and Zeiss, 2000 [28]; Mader *et al.*, 2002) [58]. Intercropping cereal with legume increases the population of soil microbes like bacteria, fungi and actinomycetes which in turn increases the quantity of nitrogen, phosphate, and potassium in the soil compared to monocropping (Dahmardeh *et al.*, 2010 [26]; Qin *et al.* 2017 [77]; Lu *et al.* 2019) [54]. Micronutrients like Cu and Fe will improve in plants under intercropping of legume and cereal with foliar spray of yield limiting factor like boron in tropical and subtropical environments (Souza *et al.* 2018) [96]. Long term effects of intercropping's would be more advantageous in soils like vertisols under semi-arid conditions of tropical and sub-tropical countries which will enhance soil organic carbon (C), available soil N, P, and K and yield of component crops (Sankar *et al.* 2011) [103]. Therefore, legumes should be included in intercropping or crop rotation systems in order to maintain and enhance soil fertility under different climatic regimes of tropical and subtropical regions of the asia and the world.

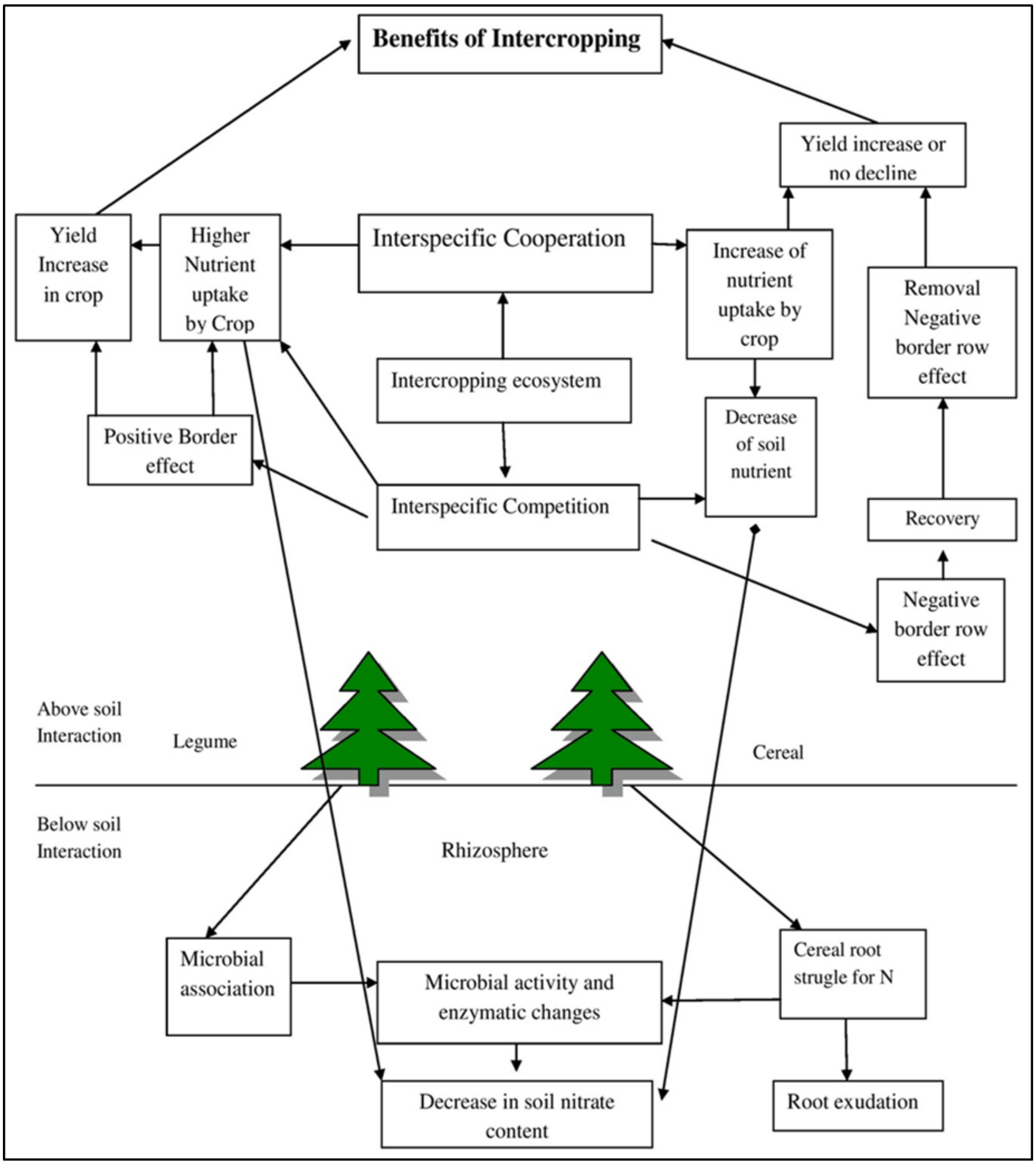



**Fig 5:** Legume cereal intercropping interaction and soil nitrate content (Modified from Zhang and Li, 2003)

## Conclusion

Scientific agriculture can be a solution to environmental issues but especially to reducing the rate of enrichment of carbon dioxide in the atmosphere. Combining legume cereal approach for small and marginal farmers of India is perfect tool for combating environment risks with low input to provide a high-quality fodder for livestock and simultaneously raising the fertility levels of soils. The crop geometry is a non-monetary use of resources by combining of legume and cereal crops for enhancement of quality as well as productivity of cultivated fodders/forages. This will not only improve the standard of living but also upgrade the environmental sustainability with financial benefits.

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