

TALL FESCUE GRASS AND WHITE CLOVER BASED MIXED CROPPING STANDS UNDER THE INFLUENCE OF POPULATION DYNAMICS

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ABSTRACT

India has been a global leader in milk production owing to its largest livestock population. However, availability of quality forage has been a major constraint in limiting livestock productivity which can be attributed to low nutritive value and productivity of conventional forage cropping systems based solely on grasses. Therefore, the present study was carried out over a period of 5 years to evaluate the productivity, nutritive value and profitability of tall fescue grass and white clover based mixed cropping systems under the influence of varying planting geometries and seed rates. Eleven treatments based on variable combinations of spacing and seed rate of tall fescue grass (20 x 30, 30 x 30 and 40 x 40 cm) and white clover (1, 2 and 3 kg/ha) were evaluated under randomized complete block design (RCBD) involving three replications of each treatment. The outcomes of the present investigation revealed that TFG 30x30 cm + WC 2.0 kg/ha-based mixed planting practice performs significantly better in terms of total forage harvest, crude protein yield and profitability attained, which can be primarily attributed to complementary relationship between forage grasses and legumes. The present investigation further revealed that total available nitrogen was considerably improved under sole planting of white clover and TFG 30x30 cm + WC 3.0 kg/ha based mixed cropping. Therefore, the current field study concluded TFG 30x30 cm + WC 2.0 kg/ha based mixed cropping system as the standout one to yield considerable higher levels of quality forage as well as enhanced farmer incomes especially in terms of gross and net returns when compared to conventional sole TFG based cropping systems.

Keywords: Forage, mixed cropping, nutritive value, tall fescue grass, white clover.

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INTRODUCTION

Indian livestock population is highly diversified with presence of 35.94% cattle, 20.45% buffalo, 27.80% goat, 13.87% sheep, 1.69% pigs and 0.05% camels across the nation (Dinesh *et al.*, 2023). With its largest share in livestock population, India stands at top in milk production, however, the average national productivity (1538 kg/yr) still lags considerably by 31.3% as compared to average global productivity (2238 kg/yr) (Singh *et al.*, 2022). Lower milk productivity in the country can be attributed primarily to shortage of dry fodder, green fodder and concentrate feed to the tune of 11%, 36% and 44%, respectively (Singh *et al.*, 2022). Conventional forage grasses-based mono-cropping systems exaggerate the situation of fodder deficiency during winter months.

Tall Fescue Grass (TFG) (*Festuca arundinacea* Schreb.) is a perennial grass suitable for plantation in pastures, grassland, and horti-pastoral conditions in subtropical to temperate regions around the globe (Yang

et al., 2023). TFG being a high-quality forage pasture with fast growth and ability to accumulate substantial amount of biomass can act as an excellent source of forage supply in winters especially under limiting moisture conditions (Franzluebbbers and Poore, 2021). The low nutritional requirements, abilities to tolerate water shortage till rooting depth of 2500 mm, considerable tolerance to adverse frost conditions and pasture pest attack makes it a great candidate for Indian forage cultivation systems especially under low input conditions (Sobotik *et al.*, 2020).

White Clover (WC) (*Trifolium repens* L.) is a significant cool season, perennial pasture legume in the world. It is adaptable to wider climatic and edaphic environments. WC has high nutritive value, better palatability with around 19% crude protein and low fibre content in its dry matter (Caradus *et al.*, 2023; Zhao *et al.*, 2023). The ability to fix atmospheric nitrogen through biological means reduces its reliance over exogenous application of nitrogenous fertilizers for sustaining its growth and development makes it an excellent

companion crop with grasses (Zhao *et al.*, 2022). WC can fix substantial amount of atmospheric nitrogen reaching up to 80-100 kg N/ha/year whereas its compact cover, strong root system can significantly prevent soil erosion and enhance soil fertility (Helios, 2021; Caradus *et al.*, 2023). Recently, WC has been advocated considerably for its candidature as a companion crop with winter forage grasses like orchard grass, ryegrass, and tall fescue grass (Liu *et al.*, 2022).

Mixed cropping system of forage crops are more agronomic and ecological sustainable and economically sounded to mono-cropping systems of forage crops (Pinto *et al.*, 2022; Tahir *et al.*, 2022; Luo *et al.*, 2023). Inclusion of legume species such as alfalfa with tall fescue grass proved to have a significant advantage on forage productivity and nutritive values (Tahir *et al.*, 2022). The growing conditions of TFG are also favourable for WC cultivation, hence inclusion of white clover may offer a great opportunity to enhance productivity, nutritive value of produce and restore soil fertility.

In mixed cropping systems, seeding density of component crops plays a pivotal role in optimizing the productivity and quality of mixed cropping cultures. Similarly, alterations in planting densities with manipulations in row spacing was proved to have a considerable impact over forage yield of legume crops (Baath *et al.*, 2024). For example, in a field investigation, increasing the seed rate of clover during frost seeding of red (11.2 kg/ha) and white clover (5.6 kg/ha) into tall fescue significantly enhanced the overall nutritive value of the mixed stand (Castillo *et al.*, 2022). Altering the seeding rates for orchard grass and alfalfa into various proportions significantly affected the forage productivity wherein 75:25 based proportion was observed to have the superior performance in terms of forage productivity and nutritive value (Xue *et al.*, 2023).

Although, the benefits of TFG and WC based mixed cropping has been widely acknowledged, still, benefits of optimizing planting geometries and seed rate alterations across mixed stands of TFG and WC are still less acknowledged especially under sub-temperate agroecology. Therefore, the present study was undertaken to evaluate the production potential of TFG with WC based cropping mixtures under varying planting geometries of TFG and seed rates of WC.

MATERIALS AND METHODS

Site description: The field investigations were carried out at Fodder Farm, Department of Genetics and Plant Breeding of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya, Palampur, India (32.1109° N, 76.5363° E and 1290.8 m above mean sea level) over a period of 5 years (2015-2020). The field study was strategically planned for investigating influence of eleven

treatments replicated thrice under a randomized complete block design (RCBD). The treatments were formulated based on suitable possible combinations of spacing and seed rate of TFG and WC, respectively. Variable spacing for TFG comprised of 20 x 30 cm, 30 x 30 cm and 40 x 40 cm, whereas for WC seed rates were 1, 2 and 3 kg/ha. Apart from these, sole plantings of TFG at 30 x 30 cm and of WC at 6 kg/ha were also included. The gross plot size for the experimental plots was 12.96 m² (3.60 x 3.60 m). The treatment details have been given in Table 1. During the experiment establishment year soil type was sandy loam, acidic in reaction (pH – 5.4), with medium organic carbon status (0.66%), low available nitrogen, medium phosphorus and potassium availability. Field preparation was done using power tiller followed by manually operated country plough. Nutrients were applied as per the recommendation of State Agriculture University (CSKHPKV, Palampur). For mixed crop stands and sole planting of TFG, nitrogen and phosphorus were applied as basal dose at the rate of 40 kg/ha and 20 kg/ha, respectively followed by 20 kg/ha of nitrogen at later stages. However, for sole WC stand a recommended application of 20 kg/ha for nitrogen and 60 kg/ha for phosphorus was done. Hand weeding was done to keep weeds well below threshold levels.

Table 1. Treatment details.

Treatments	Details
T1	TFG 20x30 cm + WC 1.0 kg/ha
T2	TFG 20x30 cm + WC 2.0 kg/ha
T3	TFG 20x30 cm + WC 3.0 kg/ha
T4	TFG 30x30 cm + WC 1.0 kg/ha
T5	TFG 30x30 cm + WC 2.0 kg/ha
T6	TFG 30x30 cm + WC 3.0 kg/ha
T7	TFG 40x40 cm + WC 1.0 kg/ha
T8	TFG 40x40 cm + WC 2.0 kg/ha
T9	TFG 40x40 cm + WC 3.0 kg/ha
T10	Sole TFG 30 x 30 cm
T11	Sole WC 6.0 kg/ha

Data collection: Yield data was recorded each year for the green forage harvest consecutively from 2015-2020. Crop was harvested with a single cut and therefore, the samples for green forage and dry matter accumulation were collected at the time of harvest. Green forage harvest data was recorded by weighing the entire biomass from the net plot area (discarding border rows from the gross plot section) (Rana and Kumar, 2014). However, in case of dry matter accumulation, 100 g of green biomass sample was collected, air dried for 72 hours followed by oven drying at 105 °C, until the sample attains a constant weight. Data observed for green forage harvest and dry matter accumulation was used to estimate harvest levels for a hectare land unit. For crude protein concentration, representative plant samples were further processed using

stainless steel grinder to 1 mm particle size (Rana and Kumar, 2014; Rana *et al.*, 2014). The grinded plant samples were further analyzed for nitrogen concentration using prescribed procedure by Jackson *et al.* (1973). The crude protein concentration was determined by multiplying plant nitrogen concentration by 6.25. Subsequently, the crude protein yield was derived using following equation:

$$\text{Crude protein yield (Mg/ha)} = \frac{\text{CP content} \times \text{dry weight accumulated}}{100}$$

Soil Analysis: A composite soil sample prior to initiation of the experiment and a sample from each treatment in all the blocks were collected after each harvest using stainless steel auger from 0-15 cm depth. Samples were air dried, grinded, and sieved using 2 mm sieve for further analysis. The soil available nitrogen was determined using standard prescribed procedures i.e., alkaline permanganate method (Subbiah and Asija, 1956).

Land Equivalent ratio: The efficacy of the mixed cropping systems was assessed using Land Equivalent Ratio (LER) index. LER is defined as the ratio of area required by respective sole crops (in this case TFG and WC) to yield the harvest equal to achieved under intercropping (Bacchi *et al.*, 2021). Total LER was obtained with the summation of LER for respective sole crops. Limit of 1 is critical for assessing the LER index, wherein LER higher than 1 indicates a benefit under mixed cropping system whereas value less than 1 defines a negative impact on crop growth and development under mixed cropping systems (Kchaou *et al.*, 2022). LER for TFG and WC was computed using below given equations:

$$\begin{aligned} \text{Land Equivalent Ratio (TFG)} &= \frac{\text{Yield of TFG under mixed cropping system}}{\text{Yield of TFG as sole crop}} \\ \text{Land Equivalent Ratio (WC)} &= \frac{\text{Yield of WC under mixed cropping system}}{\text{Yield of WC as sole crop}} \end{aligned}$$

Economic analysis: Economic viability of the experimental treatments was evaluated based on cost of inputs, operations and prices of output prevailing in market at the concurrent time. Gross returns were calculated by multiplying green forage harvest by the respective price. Net Returns and benefit cost ratio have been determined using below given equations:

$$\begin{aligned} \text{Net Returns (INR/ha)} &= \text{Gross Returns} - \text{Cost of Cultivation} \\ \text{Benefit Cost Ratio} &= \text{Gross Returns} / \text{Cost of Cultivation} \end{aligned}$$

Data analysis: The data recorded during the experiment was subjected to analysis of variance under the environment of R-Studio 4.3.1 using the prescribed procedures for RCBD. The variations among treatment means i.e., pair wise assessment was carried out with Duncan's multiple range test (DMRT) using R package "agri-colae". The "ggplot2" package was used for data

visualization. A correlation heat map was generated to study correlation among yield, nutritive and soil available nitrogen using R based packages i.e., "corrplot" and "Hmisc".

RESULTS AND DISCUSSION

Forage Harvest: Mixed cropping of TFG and WC substantially enhanced the forage harvest for the crop mixtures as compared to sole planting of the respective crops. TFG 30x30 cm + WC 2.0 kg/ha-based planting enhanced green forage harvest by 39.70 and 27.76% in comparison to sole stands of TFG and WC, respectively. Such a pattern of planting, TFG and WC resulted in at par harvests with other planting patterns except, TFG 40x40 cm + WC 1.0 kg/ha based planting wherein significantly lower forage harvest was observed for the particular grass-legume combination. Recommended spacing (30 x 30 cm) and seed rate (6 kg/ha) based sole plantings of TFG and WC were observed to have significantly lower forage harvest for the respective crops.

Dry matter accumulation: Dry matter accumulation exhibited a range of 4.62 to 7.90 Mg/ha across the different treatments in the present field investigation. Dry matter accumulation was observed to be significantly improved with mixed plantings of TFG and WC against sole planting of respective forage crops. Specifically, the TFG 20x30 cm + WC 1.0 kg/ha-based mixed-planting resulted in the highest dry matter accumulation and was at par with the planting patterns such as TFG 30x30 cm + WC 2.0 kg/ha, TFG 20x30 cm + WC 2.0 kg/ha, TFG 30x30 cm + WC 1.0 kg/ha and TFG 30x30 cm + WC 3.0 kg/ha. Dry matter accumulation for TFG 20x30 cm + WC 1.0 kg/ha-based stand was 38% higher than the sole TFG, whereas it was 71% higher in comparison to the sole WC planting-based stand (Table 2). However, accumulated dry matter declined as the spacing for the TFG was widened i.e., curtailed planting density. Mixed planting patterns also revealed reduced dry matter accumulation at higher seed rate of WC as in TFG 20x30 cm + WC 3.0 kg/ha where forage harvest was reduced significantly as compared to TFG 20x30 cm + WC 1.0 kg/ha-based stand.

Crude Protein Yield: The mixed planting pattern based on TFG 30x30 cm + WC 2.0 kg/ha resulted in considerably higher crude protein yield in comparison to sole cropping stands of respective crops. TFG 30x30 cm + WC 2.0 kg/ha-based planting was observed to have a remarkable increase of 117.38 and 35.68% in crude protein yield as compared to sole planting of both TFG and WC, respectively. Sole planting of TFG was observed to have a considerable reduction in CPY by 37.58% compared with sole planting of WC, highlighting the pivotal role of legumes in enhancing the protein output of the mixed forage harvests.

Table 2. Forage harvest and nutritive value for different treatments under the influence of TFG and WC based population dynamics.

Treatments	Green forage harvested (Mg/ha)	Dry matter accumulation (Mg/ha)	Crude Protein yield (Mg/ha)
TFG 20x30 cm + WC 1.0 kg/ha	31.31 ^{ab} ± 0.33	7.90 ^a ± 0.17	1.15 ^a ± 0.06
TFG 20x30 cm + WC 2.0 kg/ha	32.18 ^a ± 0.39	7.57 ^{ab} ± 0.27	1.16 ^a ± 0.05
TFG 20x30 cm + WC 3.0 kg/ha	32.30 ^a ± 0.44	6.97 ^{bc} ± 0.20	1.09 ^{ab} ± 0.01
TFG 30x30 cm + WC 1.0 kg/ha	31.27 ^{ab} ± 0.61	7.61 ^{ab} ± 0.18	1.18 ^a ± 0.03
TFG 30x30 cm + WC 2.0 kg/ha	32.77 ^a ± 0.74	7.63 ^{ab} ± 0.24	1.21 ^a ± 0.05
TFG 30x30 cm + WC 3.0 kg/ha	32.70 ^a ± 0.36	7.30 ^{ab} ± 0.29	1.17 ^a ± 0.03
TFG 40x40 cm + WC 1.0 kg/ha	30.38 ^b ± 0.63	7.02 ^{bc} ± 0.35	1.11 ^{ab} ± 0.10
TFG 40x40 cm + WC 2.0 kg/ha	32.11 ^a ± 0.52	6.86 ^{bc} ± 0.26	1.09 ^{ab} ± 0.03
TFG 40x40 cm + WC 3.0 kg/ha	31.63 ^{ab} ± 0.43	6.21 ^{cd} ± 0.25	1.02 ^b ± 0.02
Sole TFG 30 x 30 cm	23.45 ^d ± 0.35	5.73 ^d ± 0.27	0.56 ^d ± 0.06
Sole WC 6.0 kg/ha	25.65 ^c ± 0.53	4.62 ^c ± 0.24	0.89 ^c ± 0.04
SEm±	0.50	0.26	0.03
CD (p = 0.05)	1.49	0.77	0.11

TFG - Tall fescue grass; WC – White clover; Mg/ha – Mega gram per hectare; kg/ha – Kilogram per hectare; cm – centimeter; The data for the studied parameters have been given as mean data along with the respective standard errors. Treatments with same alphabetical letters are statistically at par with each other.

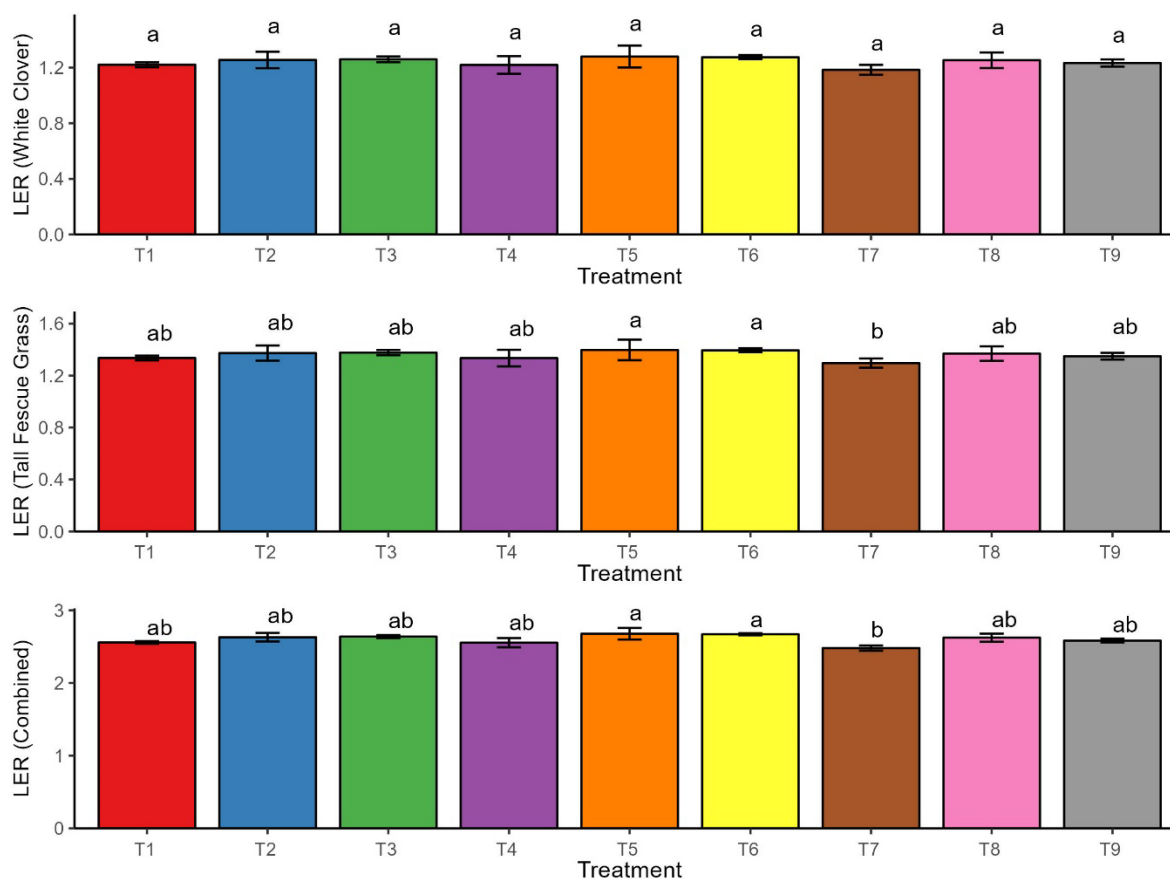


Figure 1. Influence of TFG and WC population dynamics on partial and total LER. TFG - Tall fescue grass; WC – White clover; LER – Land equivalent ratio; T1: TFG 20x30 cm + WC 1.0 kg/ha, T2: TFG 20x30 cm + WC 2.0 kg/ha; T3: TFG 20x30 cm + WC 3.0 kg/ha; T4: TFG 30x30 cm + WC 1.0 kg/ha; T5: TFG 30x30 cm + WC 2.0 kg/ha; T6: TFG 30x30 cm + WC 3.0 kg/ha; T7: TFG 40x40 cm + WC 1.0 kg/ha; T8: TFG 40x40 cm + WC 2.0 kg/ha; T9: TFG 40x40 cm + WC 3.0 kg/ha; kg/ha – Kilogram per hectare; The data for the studied parameters have been given as mean data and the standard error is represented using error bars. Treatments with same alphabetical letters are statistically at par with each other.

Land Equivalent Ratio: Partial and total LER were significantly influenced with various treatments under investigation. LER for TFG varied from 1.296 to 1.397 whereas it ranged from 1.184 to 1.280 for WC (Figure 1). For TFG, TFG 30x30 cm + WC 2.0 kg/ha-based cropping mixture recorded the highest partial LER values (1.397), whereas it was the lowest for the TFG 40x40 cm + WC 1.0 kg/ha-based combination (1.296). Similarly for the WC, the corresponding partial LER values were observed for the TFG 30x30 cm + WC 2.0 kg/ha and TFG 40x40 cm + WC 1.0 kg/ha-based cropping mixtures. The total LER values for the mixed cropping systems varied from 2.480 to 2.677. TFG 30x30 cm + WC 2.0 kg/ha based planting pattern resulted in the highest value for total LER (2.677) whereas the lowest total LER value was recorded for TFG 40x40 cm + WC 1.0 kg/ha (2.480) based planting pattern.

Economics: Crop profitability indicators such as gross, net returns and benefit cost ratio was significantly

influenced with various treatments under investigation. Gross margins (89646 INR/ha) were observed to be the highest for the TFG 30x30 cm + WC 2.0 kg/ha based cropping pattern (Table 3.). TFG 30x30 cm + WC 2.0 kg/ha based planting resulted in statistically higher gross returns in comparison to various mixed cropping stands such as TFG 40x40 cm + WC 1.0 kg/ha, sole planting of TFG and WC, respectively. In the present study, following substantially higher forage harvests, TFG 30x30 cm + WC 2.0 kg/ha based mixed cropping stand resulted in significantly better net margins amounting to 70298 INR/ha. The profits were raised by 45.10 and 28.24% with TFG 30x30 cm + WC 2.0 kg/ha-based planting as compared to sole crop stands for TFG and WC, respectively. Benefit cost ratio was also recorded to be substantially higher for TFG 30x30 cm + WC 2.0 kg/ha (3.83) based mixed cropping which was statistically better than the sole stand of TFG (3.27).

Table 3. Crop profitability for different treatments under the influence of TFG and WC based population dynamics

Treatments	Gross Returns (INR/ha)	Net Returns (INR/ha)	Benefit Cost Ratio
TFG 20x30 cm + WC 1.0 kg/ha	84981 ^{ab} ±513.0	67129 ^{ab} ±705.7	3.94 ^a ±0.0
TFG 20x30 cm + WC 2.0 kg/ha	88784 ^a ±2,818.5	69930 ^{ab} ±2,329.1	3.90 ^a ±0.0
TFG 20x30 cm + WC 3.0 kg/ha	88766 ^a ±459.7	69949 ^{ab} ±1,521.3	3.91 ^a ±0.1
TFG 30x30 cm + WC 1.0 kg/ha	86466 ^{ab} ±1,969.9	67608 ^{ab} ±2,205.6	3.77 ^a ±0.1
TFG 30x30 cm + WC 2.0 kg/ha	89646 ^a ±974.9	70298 ^a ±1,456.0	3.83 ^a ±0.0
TFG 30x30 cm + WC 3.0 kg/ha	88756 ^a ±2,849.5	69415 ^{ab} ±647.0	3.79 ^a ±0.0
TFG 40x40 cm + WC 1.0 kg/ha	82545 ^b ±384.7	64885 ^b ±2,049.6	3.85 ^a ±0.1
TFG 40x40 cm + WC 2.0 kg/ha	87592 ^{ab} ±1,905.0	68763 ^{ab} ±105.1	3.85 ^a ±0.1
TFG 40x40 cm + WC 3.0 kg/ha	86159 ^{ab} ±892.6	67318 ^{ab} ±1,847.5	3.77 ^a ±0.0
Sole TFG 30 x 30 cm	63950 ^d ±894.2	48449 ^d ±275.9	3.27 ^b ±0.0
Sole WC 6.0 kg/ha	70605 ^c ±2,668.9	54817 ^c ±1,901.8	3.64 ^a ±0.0
SEm±	1,648.2	1,573.5	0.09
CD (p = 0.05)	4,896.4	4,674.5	0.27

TFG - Tall fescue grass; WC - White clover; INR/ha - Indian National Rupees per hectare; kg/ha - Kilogram per hectare; cm - centimeter; The data for the studied parameters have been given as mean data along with the respective standard errors. Treatments with same alphabetical letters are statistically at par with each other.

Soil Parameters: Soil available nitrogen was significantly influenced with the cropping stands under investigation; however, no significant influence was observed over soil available phosphorus, potassium and soil organic carbon content. Significant increase in soil nitrogen availability was observed with sole WC planting (275 kg/ha), TFG 40x40 cm + WC 3.0 kg/ha (273 kg/ha) and TFG 30x30 cm + WC 3.0 kg/ha (272 kg/ha) based crop mixed stands as compared to sole stand of TFG (Figure 2). The soil available nitrogen was observed to be comparatively lower for the mixed cropping stands such as TFG 20x30 cm + WC 1.0 kg/ha (239 kg/ha), TFG 20x30 cm + WC 2.0 kg/ha (249 kg/ha), TFG 30x30 cm + WC 1.0 kg/ha (245 kg/ha), TFG 30x30 cm + WC 2.0 kg/ha (258 kg/ha)

and TFG 40x40 cm + WC 1.0 kg/ha (246 kg/ha). The lowest soil available nitrogen was recorded for the sole stand of TFG (220 kg/ha).

Correlation studies: Correlation studies were carried out between forage harvest, dry matter accumulation, nutritive value and the soil available nitrogen. Forage harvest was significantly related to dry matter accumulation ($r = 0.78$), crude protein yield ($r = 0.92$) in a positive manner, however a weaker positive correlation was there with available soil nitrogen ($r = 0.40$) (Figure 3). Available nitrogen in soil was also weakly correlated in a positive manner with forage harvest ($r = 0.41$), crude protein yield ($r = 0.39$) and in a negative manner with the dry matter accumulation ($r = -0.21$).

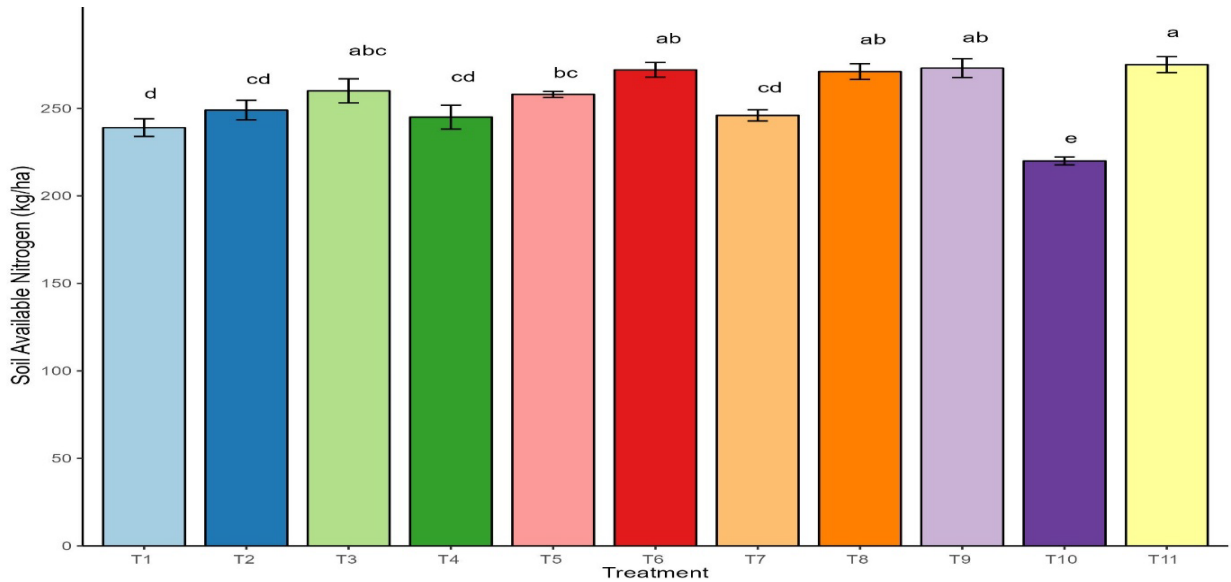


Figure 2. Influence of TFG and WC population dynamics on available soil nitrogen. T1: TFG 20x30 cm + WC 1.0 kg/ha, T2: TFG 20x30 cm + WC 2.0 kg/ha; T3: TFG 20x30 cm + WC 3.0 kg/ha; T4: TFG 30x30 cm + WC 1.0 kg/ha; T5: TFG 30x30 cm + WC 2.0 kg/ha; T6: TFG 30x30 cm + WC 3.0 kg/ha; T7: TFG 40x40 cm + WC 1.0 kg/ha; T8: TFG 40x40 cm + WC 2.0 kg/ha; T9: TFG 40x40 cm + WC 3.0 kg/ha; kg/ha – Kilogram per hectare; The data for the studied parameters have been given as mean data and the standard error is represented using error bars. Treatments with same alphabetical letters are statistically at par with each other.

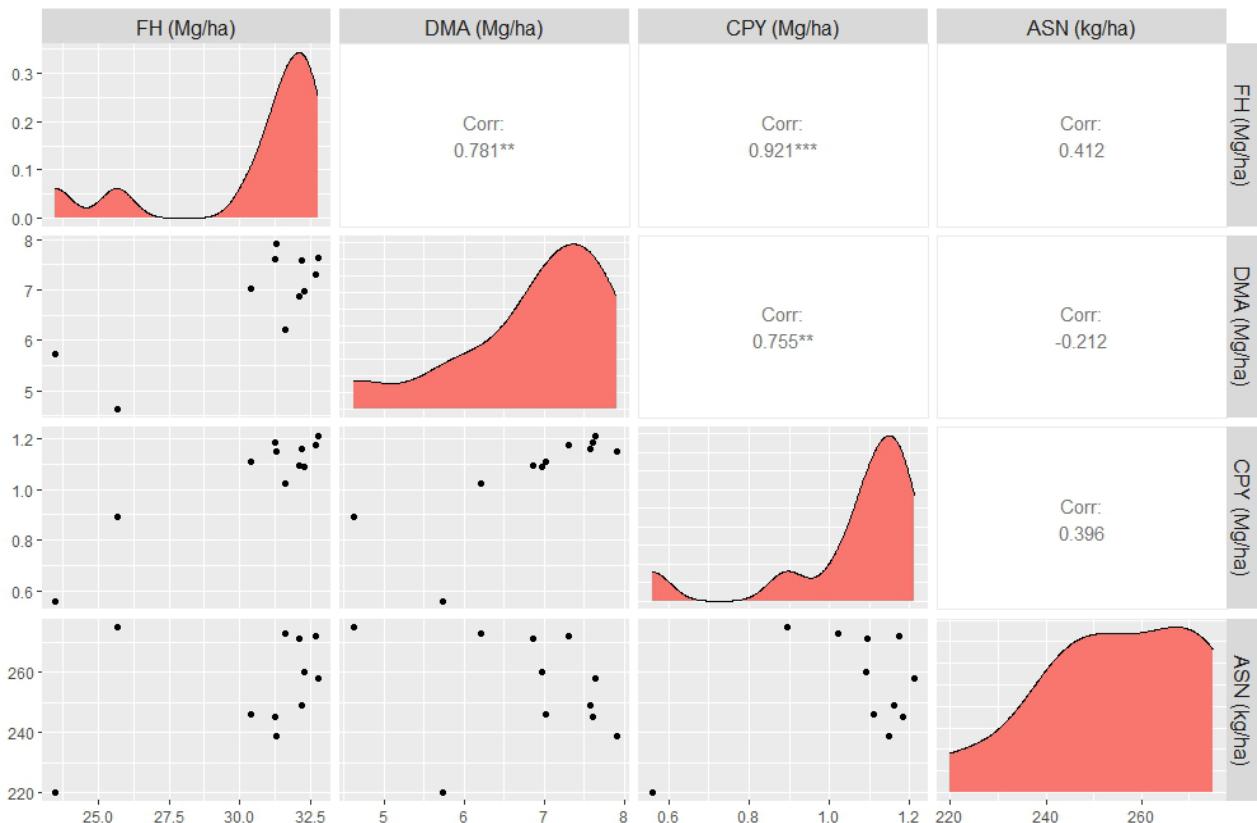


Figure 3. Correlation studies among forage harvest, quality, nutritive value and the soil available nitrogen FH - Forage Harvest, DMA - Dry Matter Accumulation, CPY - Crude Protein Yield, ASN - Available Soil Nitrogen; Mg/ha – Mega gram per hectare; kg/ha – kilogram per hectare.

DISCUSSION

Forage productivity and nutritive value is significantly affected by various factors such as genetic potential, prevailing environmental conditions and agronomic practices adopted (Tlahig *et al.*, 2024). Sowing time, seed rate, seed spacing, irrigation, weed management, exogenous input application (fertilizers, bio-stimulants etc.) and interculture operations are the primary agronomic practices adopted to manipulate forage productivity in cropping systems (Chauhan *et al.*, 2022; Das *et al.*, 2024; Devi *et al.*, 2024; Salaria *et al.*, 2024). Among agronomic practices, spacing and seed rate influences crop productivity in a considerable manner with substantial effect over population dynamics especially while considering mixed cropping systems (Yang *et al.*, 2020). Grass-legume mixed cropping systems have been reported to enhance forage productivity by a considerable manner when compared to sole counterparts. The present field investigation also revealed considerable improvements in forage productivity for TFG-WC mixtures in comparison to sole cropping of TFG and WC (Table 2). The results for the present study were in line with findings reported by Iqbal *et al.* (2018), Gelayenew *et al.* (2020) and Kumar *et al.* (2024). Enhanced forage harvests with mixed cropping of grass + legume was emphasized by Gelayenew *et al.* (2020) wherein they observed an improved harvest for elephant grass biomass with introduction of legumes i.e., vetch (*Vicia dasycarpa* and *Vicia villosa*). Furthermore, an enhanced forage harvest and nutritive value was reported by Kumar *et al.* (2024) for mixed cropping of annual ryegrass and Egyptian clover in comparison to sole counterparts. Similarly, during a field investigation reported by Iqbal *et al.* (2018), mixed sowing of crops (grasses + legume) resulted in better and effective nitrogen transformation from forage legumes to grasses through intermingling of roots consequently resulted in higher forage yield over pure stand of legumes or grasses.

Wider spacing of TFG as well as lowered seed rate for WC resulted in reduced biomass production which might have been due to reduced planting density leading to inefficient utilization of ecosystem resources in the present investigation (Table 2). The study by Iqbal *et al.* 2018 also produced considerable evidence for effect of crop spacing and seed rate over forage productivity of forage grasses and legumes. Molosiwa *et al.* (2022) also observed enhanced biomass yield for Tepary Bean (*Phaseolus acutifolius* A. Gray) with narrower spacing whereas decline in the biomass production with subsequently widened spacing. Therefore, TFG-WC based mixed cropping can be considered to be optimized practice with TFG 30x30 cm + WC 2.0 kg/ha planting geometry for significantly improved forage harvest.

Dry matter accumulation was observed to be considerably higher for sole crop of TFG in comparison

to WC which can be attributed to substantially higher innate potential of grasses for sink-based carbohydrate accumulation as compared to legumes (Table 2). Similarly, the decline in the dry matter accumulation of mixed stands with increased seed rate of WC can be attributed to lower dry matter yielding ability of forage legumes as compared to grasses (Ayele *et al.*, 2022). The experimental outcomes in terms of considerably higher forage productivity with comparatively elevated planting density of TFG as compared to WC corroborated with the findings reported by Abate *et al.* (2022). Abate *et al.* 2022 reported that 25:75 based planting proportion of alfalfa and Rhodes grass was the most appropriate mixture to significantly improve the dry matter accumulation of cropping mixtures.

Forages with high protein and low fibre content are considered to be of superior nutritive value, thereby augmenting livestock productivity in terms of meat or milk output (Sun *et al.*, 2024). Crude protein yield is a function of dry matter yield and crude protein concentration (Kumar *et al.*, 2024). The present field investigation reported considerable improvements in crude protein yield for TFG and WC based mixtures in comparison to sole crops of TFG and WC, respectively (Table 2). Inclusion of forage legumes as intercrops have been a recurrent observation across various scientific studies, consistently demonstrating their ability to augment the crude protein output of grass-legume mixtures (Bacchi *et al.*, 2021). Intercropping of legumes like alfalfa with TFG have been well observed to enhance the crude protein output of the mixed forage stands compared to sole stands of respective crops (Tahir *et al.*, 2022). Inclusion of legumes as component crops for grasses in grass-legume mixed cropping system with optimized planting geometry can be beneficial in terms of improved dry matter with better nutritive value.

LER have been a pivotal index to determine the effectiveness of mixed cropping stands in terms of their effect over respective companion crop growth and efficient utilization of environmental resources (Bacchi *et al.*, 2021). The present field investigation based results revealed that partial LER values for WC and TFG were considerably differing from each other, signifying variable level of competitiveness among crops (Figure 1). Partial LER values for TFG were greater than corresponding values for WC, indicating a competitive advantage for TFG in the intercropping systems (Maitra *et al.*, 2021). Substantially higher partial LER values for TFG justifies TFG as more dominant and competitive partner in TFG-WC intercropping systems. Furthermore, greater than 1 LER value for various cropping mixtures of TFG and WC can be attributed to substantially higher yield for TFG and WC as component crop in comparison to respective monocrops (Maitra *et al.*, 2021). Total LER values were observed to be greater than 1 for the mixed cropping systems under the present study which

emphasized an enhanced land use efficiency for the respective TFG-WC mixed crop stands. Particularly, the TFG 30x30 cm + WC 2.0 kg/ha-based cropping combination with LER ratio of 2.677 displayed a significantly higher ability for utilization of land and environmental resources for crop growth and development. LER ratio 2.677 signified that 167% of more crop land would be required by the sole cropping to produce forage harvests equal to TFG 30x30 cm + WC 2.0 kg/ha-based cropping mixture. Yield advantage for grass-legume based forage crop mixtures against sole cropping stands have been well documented across several studies (Bacchi *et al.*, 2021; Xu *et al.*, 2021; Kchaou *et al.*, 2022). Triticale and fenugreek-based cropping mixture-based study have documented the considerably higher partial LER values and competitive advantage to Triticale over fenugreek (Kchaou *et al.*, 2022).

The practicability and usefulness of any scientific advancement is judged ultimately in terms of net returns, and adoption is highly dependable on its economic feasibility (Ginwal *et al.*, 2019). Mixing the plantings of grasses with legumes was observed to have a positive influence over farmer's income, making forage cultivation more profitable. During the present field investigation, mix-cropping pattern based on TFG 30x30 cm + WC 2.0 kg/ha was observed to be the most profitable practice in terms of enhancing gross and net returns (Table 3). Similar impact of legume based mixed cropping on profitability of cereal/grass cultivation was observed by Mu *et al.* 2023, wherein alfalfa-based mixed cropping was observed to enhance the profitability of wheat cultivation in north-western China. Inclusion of red clover or Kura clover as component crops in intermediate wheatgrass was found to substantially enhance the returns generated as compared to the respective crop monocultures during a field investigation performed by Pinto *et al.* 2022 in United States of America. Improvement in forage harvest with TFG-WC mixed cropping was further reflected in better farm profits in terms of gross, net returns and benefit cost ratio.

Soil available nitrogen emerged as the predominant soil quality indicator under the present study and was significantly influenced by the TFG and WC based cropping mixtures. However, no significant influence was observed across available soil phosphorus, potassium availability and soil organic carbon content. White clover based biological nitrogen fixation was the primary cause for such a positive influence over soil nitrogen availability (Reilly *et al.*, 2022; Caradus *et al.*, 2023). Furthermore, presence of TFG as a component crop significantly elevates the competition intensity offered to the WC especially for soil available nitrogen, thus increasing its dependency over symbiotically fixed nitrogen and further improve its capability to fix

substantially higher amounts of atmospheric nitrogen (Caradus *et al.*, 2023).

Among TFG and WC based cropping combinations, soil nitrogen was found to be increasing as the seed rate for WC was increased (Figure 3). Contrary to this, soil nitrogen availability was decreased as the TFG spacing was narrowed down i.e., increasing TFG planting density. The pattern of soil nitrogen availability signified the attributes of grasses like TFG as nitrogen consumers and legumes like WC as contributors to the soil nitrogen availability due to their unique characteristics of biological nitrogen fixation in grass-legume mixed plantings (Liu *et al.*, 2023). Characteristic of grasses as primary nitrogen consumer in grass-legume mixed cropping was further accentuated by the significantly lower soil nitrogen availability under sole planting of TFG. The ability of WC as the primary contributor in grass + legume cropping combinations was also corroborated under a field experiment by Dev *et al.* 2021, wherein they observed the enhanced soil nitrogen availability with sole planting as well as with inclusion of WC in combination with grass plantings. Introduction of legumes as component crops or as sole crop were further reiterated under the present investigation as the primary contributor in for soil available nitrogen.

Conclusion: It can be concluded that with optimization of planting geometries and seeding rates for forage crops, considerably higher forage harvest as well as nutritive value of mixed cropping stands can be achieved. TFG 30x30 cm + WC 2.0 kg/ha-based planting practice was responsible for the highest forage harvest, nutritive value and profitability. TFG 30x30 cm + WC 2.0 kg/ha-based cropping stand resulted in 28% and 40% improvements in forage harvest as compared to conventional systems of monocultures for white clover and tall fescue grass. However, sole planting stand of white clover as well as mixed planting stands based on 3 kg/ha seed rate of white clover have significantly improved the soil available nitrogen status.

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