Biomass and Nutrient Accumulation of Green Manuring Legumes Terminated at Different Growth Stages

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Abstract: A field study was conducted at the experimental site of the Assosa Research Center, western Ethiopia, with the objective of generating information about the biomass and nutrient accumulation of four green manuring (GM) legume crops at different growth stages. Accordingly, factorial combinations of four legume crops [cowpea (Vigna unguiculata), soybean (Glycine max), and two common bean varieties (Black Dessie and Awash Melka) (Phaseolus vulgaris)] and three growth stages of termination (mid-vegetative, mid-flowering and pod-setting) treatments laid in a randomized complete block design were used. Significant species by growth stage treatment interaction (P<0.01) were observed in dry matter (DM) concentration, and an increase in cowpea and a decrease in Awash Melka variety were observed with a delay in termination times. In addition to the species variability in total DM production, highly significant effect of growth stage at termination was also observed, and a rise in overall DM production was recorded with the development of GM crops. Cowpea recorded the highest per plant number (5.8) and fresh mass of total (0.4 gm) and effective (0.21 gm) nodules compared to the rest, particularly at the mid-flowering stage of growth. According to the results of this study, nutrient (particularly N and K) concentrations of shoot tissue showed a declining trend with increasing plant age. After considering the species and growth stage effects on the nutritional input or contribution of GM, it was discovered that cowpea and mid-flowering stage of growth outweighed the rest.

Keywords: Concentration; Nodules; Dry Matter; Input

1. Introduction

Unlike natural systems, in which biomass production is in equilibrium with nutrient reserves, the subsistence type of agricultural system found most often in the rainfed areas of Ethiopia is typified by continual loss and net removal of soil nutrients which could cause a serious threat to the overall agricultural productivity and destabilize the natural resource base (Nair, 1996). The sustainability of such agricultural systems depends to a great extent on optimizing the balance between inflows and outflows of the nutrients. The use of inorganic fertilizers in achieving this balance for successful crop production, as well as its high costs and unreliable availability for resource poor farmers, is currently causing global concern due to environmental costs in agriculture. (Bohlool et al., 2004). Beyond sustainability considerations, increasing demand for and promising returns from organic products currently have made legume green manuring (GM) an important agronomic approach to combat soil fertility problems (Horst et al., 2001; Bohlool et al., 2004). Organic inputs from GM legumes could increase crop yield through improved nutrient supply/availability and improved soil-water holding capacity. Some researchers have found N-substitution value of GM in excess of actual green manure N accumulation, suggesting that GM N is sometimes taken up more efficiently than chemical fertilizer N or that GM modifies the soil environment, crop growth, or both such that greater crop N uptake is possible (Yadav et al., 2000). Therefore, cropping systems which include legumes as green manure could be the most efficient.

Residues of GM legume, unlike fertilizer N sources, have different effects that vary according to crop species and development stage. The chemical composition of the organic materials added into the soil as green manure has a great effect on the net N release from material or immobilization of soil mineral N. Utilization of green manure N may thus be enhanced through measures that deliberately affect the chemical composition of the materials incorporated into the soil. The chemical composition of plant material is highly affected by the developmental stage of the plant (Dahlin et al., 2005). In the case of green manure, management options which influence the developmental stage, such as cutting, could be used to adjust the quality of the plant material at the time of incorporation so that better synchrony between GM-N release and subsequent crop demand could be achieved (Cline and Silvernail, 2001; Cherr et al., 2006). In legume crops, however, cutting practices also have a range of effects on other features, such as N₂-fixation activity and abortion of nodules and roots (Wivstad, 1996). Thus, green manure crops could be chosen and managed with the aim of manipulating their quality.

According to Tandojam (2002) the selection of suitable legume species and age at termination determines the amount of biomass, N accumulation and the rate of liberation of nutrients in available forms. Termination or the soil incorporation date of GM crops could affect the fraction of plant biomass (leaf, stem, reproductive, or senesced tissue) and N if the GM responds to late-season changes in weather conditions (Cherr et al., 2006). According to Cline and Silvernail (2001) and Sainju and Singh (2001), increasing the length of the GM growing season, may or may not increase GM biomass and N content. Kong et al. (1993), however, have reported that the amount of biomass and N provided by the GM crops varies according to the growth stage at the time of soil
incorporation. Cavigelli and Thien (2003), on the other hand, suggested that plant type seems more important than residue application rate in affecting soil P availability, whereas others have reported that residue application rate is more important than plant type (Bumaya and Naylor, 1988; Li et al., 1990). Ratilla and Escalada (2006), however, did not observe any significant effect of species and timing of field legume incorporation.

The efficiency of GM crops in improving soil conditions could generally be increased through correct selection of the GM crops with higher capacity and by identifying the growth stage at which maximum top-growth and N$_2$-fixation could be achieved (Cline and Silvernail, 2001). Knowledge of GM crop DM yield and nutrient accumulation dynamics during the growth period could, therefore, provide farmers with management options aimed at maximizing the DM production for green manure and N for a subsequent crop. Such manipulation of residue quality could facilitate better synchrony between GM-N release and demand by a subsequent crop, thereby conserving N within the agricultural ecosystem (Odhibamo and Bomke, 2001). With regard to changes in biomass production and nutrient composition dynamics, most reported studies so far have been based on values of GM biomass and N content at a certain growth stage (Isse et al., 1999; Somado and Sahrawat, 2007). Sampling of different green manure crops at their varied phenological stages, however, could provide much more meaningful information for selection of appropriate GM crop and development of residue management strategies. In this context, it is important to study the relationships between residual attributes of different legumes and their different phenological stages. This study was, therefore, initiated to generate information about GM biomass yield and the nutrient accumulation of four legume species terminated at their different phenological stages in the soil and climatic conditions of areas around Assosa.

2. Materials and Methods

2.1. Description of the Study Area

The study was carried out in 2007 at the experimental site of the Assosa Research Center, western Ethiopia. According to the classification of EARO (1999), the agroclimate of the area falls under sub-humid lowland with a mono-modal rainfall pattern. The area receives an annual rainfall of 1275 mm. The annual mean maximum temperature reaches 28 °C while the mean minimum temperature is 15 °C. Rainfall and weather data during the growing season are presented in Table 1. The dominant soil at and around the Research Center is reddish brown, Nitosols, which, according to pre-sowing soil test results, is low in fertility especially in N, P and organic matter (Table 2).

Table 1. Mean monthly weather data for Assosa in the 2007 cropping season.

| Month  | Rainfall (mm) | Mean temperature (°C) | Relative humidity (%) | Evapo-transpiration (mm day$^{-1}$) | Sunshine hours day$^{-1}$ |
|--------|---------------|-----------------------|-----------------------|-------------------------------------|--------------------------|
|        |               | Max                   | Min                   |                                     |                          |
| April  | 47.9          | 30.4                  | 17.4                  | 48.62                               | 11.4                     | 7.48                    |
| May    | 82.6          | 28                    | 17.3                  | 50.68                               | 8.9                      | 5.4                     |
| June   | 178.9         | 24.1                  | 16.4                  | 80.46                               | 2.94                     | 4.4                     |
| July   | 178.9         | 23.2                  | 15.9                  | 85.56                               | 2.35                     | 3.32                    |
| August | NA            | NA                    | NA                    | NA                                  | NA                       | NA                      |
| September | 224        | 24.1                  | 15.6                  | NA                                  | NA                       | NA                      |
| October| 147.5         | 26.7                  | 13.2                  | 64.62                               | 3.7                      | 6                       |
| November | 16.1         | 27.3                  | 12.5                  | 62.32                               | 5.9                      | 7.9                     |

NA = Data not available

Source: Assosa Meteorological Service Branch Office.

2.2. Experimental Treatments and Procedures

A factorial combination of four legume species [cowpea, (Vigna unguiculata), soybean (Glycine max) and two common bean varieties (Black Desse and Awash Melka) (Phaseolus vulgaris)] and three growth stages of termination viz., mid-vegetative, mid-flowering and pod-setting (Table 3), resulting in a total of 12 treatments, were applied on plots of 4.5 m by 6 m. The experiment was laid out in two factors randomized complete block design (RCBD) and was replicated three times. Before the sowing of each crop, the land was plowed to prepare a suitable seed bed and then seeds of the GM legume crops were sown by hand drilling at spacing of 40 by 10 cm.

Table 2. Properties of the soil as analyzed before legume planting.

| Parameters  | Soil test values |
|-------------|------------------|
| pH (H$_2$O) | 5.9              |
| Organic C (g C kg$^{-1}$) | 19.7 |
| Total N (g kg$^{-1}$) | 1.4 |
| Available P (mg kg$^{-1}$) | 1.84 |
| EC (dS/m) | 0.14 |
| CEC (Cmol(+)/kg) | 25 |
| K (mg kg$^{-1}$) | 37.14 |
| Ca (Cmol(+)/kg) | 6.34 |
| Mg (Cmol(+)/kg) | 3.67 |
| Na (Cmol(+)/kg) | 0.16 |
| Base Sa. (%) | 40.6 |
### Table 3. Description of experimental treatments.

| Legume species | Growth stage at termination | Description of growth stage |
|----------------|----------------------------|-----------------------------|
| Cowpea         | Mid-vegetative             | 8 weeks after emergence (WAE) |
|                | Mid-flowering              | 11 WAE                      |
|                | Pod-setting                | 14 WAE                      |
| Common bean\(^1\) | Mid-vegetative             | 5 WAE                       |
|                | Mid-flowering              | 8 WAE                       |
|                | Pod-setting                | 11 WAE                      |
| Common bean\(^2\) | Mid-vegetative             | 5 WAE                       |
|                | Mid-flowering              | 8 WAE                       |
|                | Pod-setting                | 11 WAE                      |
| Soybean        | Mid-vegetative             | 8 WAE                       |
|                | Mid-flowering              | 11 WAE                      |
|                | Pod-setting                | 14 WAE                      |

\(^1\) Black Dessie Variety, \(^2\) Awash Melka Variety

### 2.3. Sampling, Data Collection and Analysis

#### 2.3.1. Data Collection

From legume crops grown in a uniform inter- and intra-row spacing of 40 cm by 10 cm, the biomass yield was estimated by mowing the foliage from a 1 m x 1 m quadrat of each plot at the respective termination stage. The fresh and dry foliage weights were taken immediately and after oven drying (at 105 °C for 48 hrs), and were later extrapolated to t ha\(^{-1}\). To determine the per plant production of total and effective nodulation, nodules which developed a pink-brown internal color after slice opening of the nodules (Gwata et al., 2003); number and the fresh weight of each nodule were recorded after careful uprooting of 5 randomly taken plants from each plot at the respective stage of termination.

#### 2.3.2. Tissue Sampling and Analysis

Shoot materials of GM legumes sampled from each plot at respective growth stages were analyzed for N, P, K and Ca concentrations. Nitrogen concentration in dry matter (DM) was determined using the Micro-Khieldahl method (AOAC, 1994). To determine the P in plant tissue, colorimetric measurement was taken, while K and Ca were determined by flame photometry and atomic absorption spectrometry respectively (Rhoades, 1982). Total GM N, P, K and Ca inputs were calculated by multiplying the concentration with the respective total DM yield.

### 2.3.3. Statistical Analysis

Analysis of variance was carried out using MSTATC statistical software followed by mean separation using the least significant difference (LSD) test and correlation test both at 1 and 5% probability levels.

### 3. Results and Discussion

#### 3.1. Species and Growth Stage Effects on Biomass Production

Total fresh biomass production was observed to vary significantly (P<0.01) among the GM legumes (Table 4). Cowpea produced the highest biomass (6.85 t ha\(^{-1}\)) when averaged across growth stages. The biomass yield of cowpea is as high as more than double that of Black Dessie and Awash Melkas common bean varieties (Table 5). Growth stage at termination in the present study, however, did not affect (P>0.05) the fresh biomass weight. In this study, highly significant species by termination time treatment interaction was observed in DM content, and an increase in cowpea and a decrease in Awash Melkas were recorded with a delay in termination times (Figure 1). In this case, cowpea contained the lowest DM content, which may be attributable to dilution of the material because of large biomass production (Teasdale et al., 2004).

![Figure 1. Interaction effect of species and growth stage on dry matter content (%) Vertical bars represent LSD values for interaction effect at 1% probability level.](image-url)
After considering total DM inputs of GM crops, the highest amount (P<0.01) was recorded by cowpea (1.86 t ha\(^{-1}\)) followed by soybean (1.42 t ha\(^{-1}\)) when averaged across green manure termination stages (Table 5). A significant (P<0.05) effect of growth stage at termination of GM legumes was also observed with regard to total DM input (Table 4), although a marked difference in the pattern of change in DM yield of legumes may be attributable to species variability. In this study, DM yield increased significantly as termination was delayed from mid-vegetative to flowering stages of growth. Similarly, Brandt (1996) found the average biomass of black lentil doubled from early bud to full-bloom stages. Martin et al. (1976), however, reported that the DM yield of crotalaria reached its peak at early-flowering period, similar to the case in cowpea in this study.

Table 4. Mean square estimates for biomass yield, nodules per plant and nutrient concentrations and inputs of legume species as analyzed for two factors randomized complete block design.

| Parameters studied | Mean squares for source of variation† | Sampling stage (2) | LS X SS (6) | Error (22) |
|--------------------|--------------------------------------|--------------------|-------------|------------|
| Fresh biomass      | 36.74**                             | 52.97              | 1.52        | 1.46       |
| % DM content       | 108.56**                            | 2.23               | 47.69**     | 11.59      |
| Total dry matter yield | 1.96**                              | 0.42*              | 0.11        | 0.10       |
| Nodules/plant      | 19.58**                             | 1.18               | 2.57*       | 1.03       |
| Wt. fresh nodules/plant | 0.05**                              | 0.03**             | 0.01        | 0.004      |
| Effective nodules/plant | 5.14*                               | 0.88               | 0.92*       | 0.33       |
| Wt. effective nodules/plant | 0.05*                               | 0.02**             | 0.008*      | 0.003      |
| % N concentration  | 1.29*                               | 0.20*              | 0.33**      | 0.05       |
| %P concentration   | 0.03**                              | 0.009*             | 0.006*      | 0.003      |
| %K concentration   | 0.32                                | 1.16*              | 1.16        | 0.29       |
| %Ca concentration  | 6.72**                              | 2.13               | 1.26        | 1.04       |
| Total N input      | 1642.40**                           | 333.52*            | 215.11      | 101.08     |
| Total P input      | 16.19**                             | 2.31               | 2.34        | 2.15       |
| Total K input      | 397.79*                             | 73.01              | 79.56       | 101.76     |
| Total Ca input     | 5953.38**                           | 2006.86**          | 501.97      | 237.84     |

†Black Dessie Variety, ‡Awas Melka Variety, †Figures in parenthesis = degrees of freedom; * = Significant at P = 0.05; ** = Significant at P = 0.01.

Table 5. Effects of sampling stages on fresh biomass and total dry matter production of the legume species.

| Legume species (LS) | Growth stage (GS) | Mean* |
|---------------------|-------------------|-------|
|                     | Mid-vegetative    | Mid-flowering | Pod-setting |
| Fresh biomass (FB) production (t ha\(^{-1}\)) | 7.31          | 6.87            | 6.37          | 6.85a        |
| Cowpea              | 1.77              | 2.42            | 3.58          | 2.59c        |
| Common bean\(^{1}\) | 1.74              | 2.90            | 3.04          | 2.56c        |
| Common bean\(^{2}\) | 3.64              | 3.89            | 5.44          | 4.32b        |
| Soybean             | 3.62              | 4.02            | 4.61          |              |
| Total dry matter (DM) production (t ha\(^{-1}\)) | 1.60          | 2.10            | 1.90          | 1.86a        |
| Cowpea              | 0.61              | 0.78            | 1.24          | 0.87c        |
| Common bean\(^{1}\) | 0.90              | 0.93            | 0.94          | 0.92c        |
| Soybean             | 1.21              | 1.33            | 1.74          | 1.42b        |
| Mean*              | 1.08b             | 1.28ab          | 1.42a         |              |
| LSD                 | LS (FB)           | GS (FB)         | LS (DM)       | GS (DM)      |
| (0.01)              | 1.60              | NS              | 0.43          | NS           |
| (0.05)              | -                 | -               | -             | 0.27         |

3.2. Nodulation Pattern of Legumes at Different Phonological Stages

Nodulation of legumes has been used by many workers as an indirect measurement (indicator) of N\(_2\)-fixation (Johnson and Hume, 1983; Wolyn et al., 1989). In this study, significant (P<0.05) species by growth stage treatment combined effect was observed in the total number of root nodules whereby cowpea at mid-flowering stage of growth recorded the top amount, and declining trends were observed for the remaining species in the subsequent samplings (Table 6), ascribable to genetic variation and to N\(_2\)-fixing ability involving both...
legume species and rhizobium components of the symbiotic association (Sanginga et al., 2000). A trend similar to the total number of nodules was also observed in nodule fresh mass while considering the effects of species variability and growth stage (Figure 2). Similar results were reported by Elahi et al. (2004) who observed a decline in number and fresh weight of nodules after the flowering stage of growth in mungbean cultivars.

Significant (P≤0.05) interaction effects of species and growth stage treatments were also observed in this study both in the number and weight of effective nodules (Table 4), where cowpea and soybean recorded their maximum number and mass of effective nodules at the mid-flowering stage of growth and both common bean varieties recorded their maximum at the mid-vegetative stage of growth (Table 7). The number and weight of effective nodules in this study are found to be highly correlated with the number and weight of total nodules (r = 0.91 and r = 0.75, respectively) (Table 9). Generally declining values of indirect measures of N₂-fixation (nodulation pattern) after the flowering stage of growth have been documented extensively (Swaraj and Garay, 1977; Johnson and Hume, 1983; Wolyn et al., 1989). The number and mass of total and effective nodules were found to correlate more to the total phytomass N input than to change in DM yield with plant development (Table 8), attributable to sink strength (e.g., nodules versus pods) (Maschner, 1995).

Table 6. Interaction effects of species and growth stage on number of total nodules per plant.

| Legume species (LS) | Growth stage (GS) | Mid-vegetative | Mid-flowering | Pod-setting | Mean |
|---------------------|-------------------|----------------|--------------|-------------|------|
| Cowpea              | 3.2cd             | 5.8a           | 5.2ab        | 4.7         |
| Common bean¹        | 2.3cde            | 1.9de          | 1.4e         | 1.9         |
| Common bean²        | 2.2cde            | 1.1e           | 1.1e         | 1.5         |
| Soybean             | 3.5cd             | 3.9e           | 3.4cde       | 3.3         |
| Mean                | 2.8               | 3.2            | 2.5          |             |
| LSD                 | 1.72              | (0.01)         |              | (0.05)      |

Values followed by the same letter are non-significant at 5% probability level.
¹ Black Dessie Variety, ² Awas Melka Variety, NS=non-significant; LSXGS=treatment interaction.

Table 7. Interaction effects of species and growth stage on number and fresh weight (g) of effective nodules per plant.

| Legume species (LS) | Growth stage (GS) | Nodule number (NN)/plant | Mid-vegetative | Mid-flowering | Pod-setting | Mean |
|---------------------|-------------------|--------------------------|----------------|--------------|-------------|------|
| Cowpea              | 1.2bcd            | 2.2a                     | 1.9ab          | 1.8          |
| Common bean¹        | 0.9cde            | 0.0e                     | 0.0e           | 0.3          |
| Common bean²        | 0.9cde            | 0.0e                     | 0.0e           | 0.3          |
| Soybean             | 1.7abc            | 1.9abc                   | 0.7de          | 1.4          |
| Mean                | 1.2               | 1.0                      | 0.6           |             |

| Fresh weight (FW) of nodules (g/plant) | Cowpea | Common bean¹ | Common bean² | Soybean | Mean | LSD |
|---------------------------------------|--------|--------------|--------------|---------|------|-----|
|                                      | 0.13abc| 0.10bc       | 0.10bc       | 0.22a   | 0.14 | 0.04|
| Mean                                 | 0.14   | 0.10         | 0.06         |         |      |     |

Means within a row or column followed by the same letter are not significantly different at the specified probability levels.
¹ Black Dessie Variety, ² Awas Melka Variety.
3.3. Effect of Legume Growth Stage on Nutrient Composition and Input

3.3.1. Nitrogen Content and Total Input

In this study, a species by termination stage interaction effect (P<0.05) on shoot tissue N concentration was observed. Both common bean varieties recorded a peak in N content at the vegetative growth stage after which it nearly stabilized with a further delay in termination (Figure 3). Soybean also followed a trend similar to the former crops in its N concentration, but was found to be the lowest throughout the growing season. The N concentration of cowpea, which was the lowest at the early growth phase, rose at the mid-flowering stage and declined thereafter, corresponding to nodulation pattern, which most likely is an expression of sink competition for photosynthates between the developing pods and the N\textsubscript{2}-fixing root nodules (Marschner, 1995). The findings of this study, however, contradicted the observations made by Sainju et al. (2001) who observed on kill date effect on N concentration of hairy vetch and winter weeds.

The total N input or contribution, the product of tissue N concentration and total DM yield from GM legumes showed a marked difference (P<0.01) between legume species grown (Table 4), corresponding to the differential biomass production (Table 5 and 8). In this regard, maximum DM production in cowpea contributed to a great extent to the rise in its total N input compared to its tissue N content; and in comparison with black haricot bean which yielded the lowest levels of DM and total N. Similar contributions of biomass production to the total N inputs were observed by Wagger (1989) and Teasdale et al. (2004) in hairy vetch. The difference in the tissue N concentration and total N inputs between the species could, therefore, be attributable to differential potential biomass productivity and N\textsubscript{2}-fixation ability of the species (Odhiambo and Bomke, 2001; Njunie et al., 2004). Moreover, in plants grown on low-N field soils, like that of this study (Table 1), the total plant or biomass N contribution could be attributable to N derived from the N\textsubscript{2}-fixation (Wolyn et al., 1989).
Growth stage of the GM legumes at termination was also found to significantly (P≤0.01) affect the total N input following the pattern similar to its effect on total DM production, as indicated by a highly significant correlation between them (r = 0.93). The maximum N input (43.17 kg ha⁻¹) was recorded during the latter stage of termination (pod-setting) at which DM yield attained its peak (1.42 t ha⁻¹) (Table 5 and 8). Kong et al. (1993) reported similar observations, stating that the amount of N provided by the GM crops varied according to the growth stage at the time of incorporation, corresponding to the biomass production. Ranells and Wagger (1992) in North Carolina, however, reported an opposing trend in crimson clover, where the N input declined as DM production increased with the maturity of crimson clover from the late vegetative to early seed set growth stages.

Since the N accumulation is a major determinant of the ability of organic residues to supply nutrients, though there are other modifying factors (Myers et al., 1994), cowpea at the mid-flowering stage of growth could be considered a superior GM crop to provide GM-N. This result corroborates the results reported by Odhiambo and Bomke (2001), who observed peak N inputs at the flowering stage of growth while examining the potential of crimson clover (Trifolium incarnatum L.) and narrow leaf vetch (Vicia angustifolia L.) as legume green manure.

Table 8. Species and growth stage effects on estimated total nitrogen input (kg ha⁻¹).

| Legume species (LS) | Growth stage (GS) | Mid-vegetative | Mid-flowering | Pod-setting | Mean |
|---------------------|-------------------|----------------|---------------|-------------|------|
| Cowpea              |                   | 42.67          | 71.23         | 62.49       | 58.80a |
| Common bean¹        |                   | 22.59          | 26.34         | 39.59       | 29.81b |
| Common bean²        |                   | 33.99          | 31.53         | 28.43       | 31.32b |
| Soybean             |                   | 33.14          | 34.20         | 42.19       | 36.51b |
| Mean                |                   | 33.10b         | 40.83ab       | 43.17a      |      |

LSD

| (0.01) | 13.4 | NS |
| (0.05) | 8.53 |

Means within a row or column followed by the same letter are not significantly different at the specified probability levels.

¹Black Dessie Variety, ²Awash Melka Variety.
Table 9. Correlation coefficients between growth parameters of green manuring legume crops.

| Parameters | NTN | WTN | NEN | WEN | TDM | TNI |
|------------|-----|-----|-----|-----|-----|-----|
| NTN        | 1   | 0.85** | 0.91** | 0.79** | 0.37* | 0.44** |
| WTN        | 1   | 0.80** | 0.75** | 0.34* | 0.49** |
| NEN        | 1   | 0.90** | 0.90** | 0.40* | 0.49** |
| WEN        | 1   | 0.39* | 0.48** |
| TDM        | 1   | 0.93** |
| TNI        | 1   |       |

* = Significant at P = 0.05; ** = Significant at P = 0.01; NTN = Number of total nodules; WTN = Weight of total nodules; NEN = Number of effective nodules; WEN = Weight of effective nodules; TDM = Total dry matter; TNI = Total N input

3.3.2. Phosphorus and Potassium Compositions and Inputs

In this study significant interaction (P≤0.05) of the species according to growth stage treatments was observed in tissue P concentration (Table 4), where Awash Melka variety showed an increase followed by a decrease at and after the mid-flowering stage of growth. Tissue P concentration in soybean, however, showed a marginal and linear decrease as termination was delayed (Figure 4). After considering the total P input of green manure, a significant difference (P≤0.01) between species was observed, where cowpea contributed the highest amount (6.84 kg P ha⁻¹) (Table 10). The total P input, however, was not found to vary (P>0.05) due to growth stage effect.

![Figure 4. Interaction effect of species and growth stage on shoot P concentration (%) Vertical bars represent LSD values for interaction effect at 5% probability level.](image)

Even though the shoot K concentration of GM crops in this study was found to be non-significant (P>0.05), growth stage at termination was observed to significantly affect (P≤0.05) the tissue K concentration (Table 4). Declining trends of shoot K composition in the subsequent samplings of GM legumes right after the initial termination observed in this study (Figure 5) were found to be in agreement with the findings of Franchini et al. (2003) and Njunie et al. (2004) who reported higher K contents from foliage of legume crops during earlier stages of growth. In spite of the non-significant species difference in tissue K concentration observed in this study, significant differences (P≤0.05) between the legume crops were, however, recorded in total K input, where cowpea contributed the highest amount (24.02 kg K ha⁻¹) (Table 10). Growth stage of green manure crops at soil incorporation did not cause significant differences (P>0.05) in total K input.
The other hand, has reported that the Ca content of plants varies at between 0.1 and >0.5% of tissue dry weight depending on the growing condition, plant species and plant organ. While determining the total Ca input of the GM legumes in this study, significant difference (P<0.01) was also observed between GM crops, where cowpea contributed the highest amount (79.38 kg Ca ha⁻¹). Difference in total Ca input was also observed due to the effect of growth stage at termination, where an increase in the overall Ca input was observed as termination was delayed (Table 11).

Table 10. Species effect on estimated total phosphorus and potassium inputs (kg ha⁻¹).

| Legume species (LS) | Growth stage (GS) | Mean |
|---------------------|-------------------|------|
|                     | Mid-vegetative    | Mid-flowering | Pod-setting |      |
| Phosphorus (P)      |                   |                 |             |      |
| Cowpea              | 6.24              | 7.19           | 7.13        | 6.84a|
| Common bean¹        | 2.86              | 3.19           | 5.34        | 3.86b|
| Common bean²        | 4.04              | 4.97           | 3.47        | 4.16b|
| Soybean             | 4.16              | 4.47           | 5.25        | 4.76b|
| Mean                | 4.45              | 4.95           | 5.32        |      |
| Potassium (K)       |                   |                 |             |      |
| Cowpea              | 29.28             | 28.95          | 13.84       | 24.02a|
| Black Dessie        | 7.69              | 5.84           | 11.74       | 8.42b|
| Awash Melka         | 16.74             | 9.91           | 10.21       | 12.29b|
| Soybean             | 15.51             | 12.67          | 13.85       | 14.01ab|
| Mean                | 17.31             | 14.34          | 12.42       |      |

LSD

| (0.01)   | 1.19 | NS   | 10.24 | NS   |
| (0.05)   | -    | NS   | -     | NS   |

Means within a column followed by the same letter are not significantly different at the specified probability levels.

¹Black Dessie Variety, ²Awash Melka Variety.
Table 11. Species and growth stage effects on tissue Ca concentration and total input (kg ha\(^{-1}\)).

| Legume species (LS) | Growth stage (GS) | % Ca concentration (CC) | Total Ca (TC) input (kg ha\(^{-1}\)) |
|---------------------|-------------------|-------------------------|--------------------------------------|
|                     | Mid-vegetative    | Mid-flowering           | Pod-setting                          | Mean                      |
| Cowpea              | 2.21              | 4.30                    | 5.61                                 | 4.37\(a\)                |
| Common bean\(^1\)   | 2.58              | 1.91                    | 2.62                                 | 2.37\(b\)                |
| Common bean\(^2\)   | 2.86              | 3.49                    | 3.04                                 | 3.13\(ab\)              |
| Soybean             | 2.20              | 3.23                    | 2.93                                 | 2.79\(b\)                |
| Mean                | 2.72              | 3.23                    | 3.55                                 |                           |
| Cowpea              | 46.86             | 85.58                   | 105.69                               | 79.38\(a\)              |
| Common bean\(^1\)   | 16.08             | 14.72                   | 32.69                                | 21.16\(b\)              |
| Common bean\(^2\)   | 26.19             | 34.03                   | 28.67                                | 29.61\(b\)              |
| Soybean             | 26.84             | 43.38                   | 51.75                                | 40.66\(b\)              |
| Mean                | 28.99\(b\)       | 44.43\(a\)             | 54.68\(a\)                           |                           |

\(\text{LSD LS (CC)}\) 1.35, NS; 20.49, NS
\(\text{LSD GS (CC)}\) - NS - 13.06 NS
\(\text{LSD LS (TC)}\) - NS - 13.06 NS
\(\text{LSD GS (TC)}\) - NS - 13.06 NS

Means within a row or column followed by the same letter are not significantly different at the specified probability levels.

\(^1\)Black Dessie Variety, \(^2\)Awas Melka Variety.

4. Conclusion
The nutrient contents of shoot tissues, mainly N, P and K varied according to GM crops which generally decreased with increasing plant age, confirming that the nutritional inputs of green manuring crops depend on the species and age at termination. The total N input of the GM legumes was found to be significantly affected by growth stage at termination, where termination at early (mid-vegetative) stage of growth contributed the lowest total N, whereas the latest stage of termination contributed the maximum. From the results of this study, it could, therefore, be concluded that cowpea used as green manure if incorporated into soil at its flowering stage of growth may generally be promising in the nutrient cycling potential of crops as it could make available the largest amount of plant nutrients, namely organic matter, N, P, K and Ca, compared to the rest, owing to deep rooting characteristics and biomass production. In this regard, further delay in the termination of cowpea beyond the flowering stage of growth could result in no additional benefit with respect to total N input from the phytomass.

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