Inoculation and phosphorus fertilizer improve food-feed traits of grain legumes in mixed crop-livestock systems of Ethiopia

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ABSTRACT

Grain legumes play an important role as source of food and feed in smallholder mixed systems. They also contribute to soil fertility improvement through biological nitrogen fixation. Although rhizobium inoculation and phosphorus fertilizer are known to improve grain yield of legumes, information is limited on the effect of this practice on the yield and fodder quality of the haulm. This study was conducted to evaluate the effects of rhizobium inoculation (I) and phosphorus fertilizer (P) on yield and nutritional quality of grains and haulms of grain legumes (faba bean, chickpea, common bean and soybean) on farm across diverse agroecological locations in the Ethiopian highlands. The crops were subjected to four treatments [+I, +P, −I +P and a negative control (−P−I)] at multiple locations on farm during the main cropping season in 2016. Yield data was recorded during grain harvesting, and subsequently representative samples of grains and haulms were collected and analyzed for quality variables. Effects of the treatments were significant (P < 0.05) with 30% increase on grain yield for all studied crops and 28% increase on haulm dry matter yield for faba bean, common bean and soybean. Crude protein (CP) and in vitro organic matter digestibility (IVOMD) values of faba bean, common bean and soybean haulms were higher (P < 0.05); and neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were lower (P < 0.05) for the treatments than the control. The haulm CP content and IVOMD of chickpea also responded positively (P < 0.05) to the treatments. The current results demonstrated the possibility of improving both yield and quality of grains and haulms of grain legumes with the application of efficient rhizobium inocula and P fertilization. This practice offers an opportunity for smallholders in the crop-livestock system to improve the food-feed traits of grain legumes with minimal input and environmental footprint.

1. Introduction

Food and feed demand in Ethiopia continue to grow at a high rate due to population pressure and high yield gaps both in crop and livestock productivity. Grain legumes are the second most produced crops in the country next to cereals. They are cultivated on more than 1.5 million hectares of land annually, mainly by smallholder farmers in the mixed crop-livestock farming system for food, feed and soil fertility improvement through symbiotic biological nitrogen fixation (CSA, 2015). The role of grain legumes to sustain the smallholder system is becoming indispensable as declining soil fertility continues to be a major challenge in the Ethiopian highlands due to land degradation and erosion (Tesfahunegn et al., 2011; Haileslassie et al., 2005). Nitrogen and P are among the main limiting nutrients in soil systems in Ethiopia that create high yield gaps (Tamene et al., 2017; Wolde-meskel et al., 2018). For instance, Haileslassie et al. (2005) estimated that arable soil nutrients were depleted annually at a rate of 122 kg N ha⁻¹, 13 kg P ha⁻¹, 82 kg K ha⁻¹; while inflow of nutrients from artificial fertilizer application is minimal (less than 20 kg ha⁻¹ y⁻¹ for N) (CSA, 2015). Under this scenario, a better integration of grain legumes, coupled with improved agronomic practices that enhance biological N fixation, will enable to exploit the full potential of crop legumes in smallholder systems.

The efficiency with which atmospheric N is fixed by legumes as well as the total amount of N incorporated into the soil system can be considerably increased by inoculating the seeds with effective strains of

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rhizobium (Giller, 2001; Yakubu et al., 2010). However, low P content of the soil may reduce symbiotic efficiency of the legume crop (Yakubu et al., 2010). Studies have shown that inoculation with effective rhizobium strains and small amount of P fertilizer significantly increases grain yields of legumes (Rurangwa et al., 2018; Wolde-meskel et al., 2018). This practice appears to play an important role for the sustainable intensification of smallholder systems in Sub-Saharan Africa because of its potential to enhance both soil fertility and crop yields with low cost (van Heerwaarden et al., 2018).

The livelihood of smallholder farmers in the mixed system is dependent on both crop and livestock production. In most cases, the livestock and crop sub systems have a strong interdependence and complementarities (Getachew et al., 1993; Solomon et al., 2009). Residues from crop cultivation have increasingly become the major source of feed for livestock (Bayush et al., 2008; Malede and Takele, 2014), contributing up to 30–80% of the total feed dry matter available for animals in the highlands of Ethiopia (Africa Rising, 2014). Haulms of grain legumes contain higher crude protein than cereal residues and their contribution to the nutrition of livestock in the smallholder systems is considerable (Lopez et al., 2005; Tolera, 2008). This is especially true during the dry months when green fodder is unavailable and farmers are required to keep strong draft oxen for land preparation at the onset of the rains. In spite of this, agronomic and breeding activities mainly focus on improving grain yields and overlook the importance of residue yield and quality for smallholders.

While inoculation with effective rhizobial inoculant and P fertilizer is demonstrated to increase grain yield in legumes (Deaker et al., 2004; van Heerwaarden et al., 2018; Wolde-meskel et al., 2018), there are few studies on how it affects fodder trait variables (haulm yield and quality) in grain legumes. At the outset of this research, we hypothesized that N fixation due to inoculation and P fertilizer would considerably increase nutrient accumulation in the plant system, which would positively affect the fodder trait of the haulm in terms of yield, crude protein content and digestibility. This will in turn contribute to livestock productivity. To test this hypothesis, an extensive on-farm trial involving rhizobium inoculation and P fertilizer treatments was conducted. Here, we report the effect of the treatments [I, P and/or I + P] on whole plant productivity, grain and haulm yield and haulm fodder quality on four grain legumes namely, chickpea, common bean, faba bean and soybean. The study was conducted across a large number of smallholder farms covering diverse soil fertility and agroecological conditions over four regions in Ethiopia namely, Amhara, Benshangul Gumuz, Oromia and Southern Nations Nationalities and Peoples’ Region. The results are discussed with respect to the potential of the treatments [I, P and/or I + P] to enhance grain-haulm yield and feed quality of legumes, and their implications for wide scale promotion and intensification of crop-livestock systems within smallholder systems.

2. Materials and methods

2.1. Study sites

The study was conducted in 16 purposely selected districts across four regional states of Ethiopia in the 2016 cropping season. The selection was based on their representativeness and potential for grain legume production. The distribution of the study districts across the four regions is indicated in Fig. 1. The districts have been used as action sites for the N2Africa project, a large scale research-in-development project focusing on putting N fixation to work for smallholder farmers growing legume crops in Africa. Four legume crops of major economic importance were considered for the study and the districts were tagged with the different grain legumes based on the potential of the areas as shown in Table 1 and Fig. 1.
seeds were planted on the same day they were inoculated. All other crop husbandry practices were similar for the four treatments and according to the recommended agronomic packages. Overall, a total of 104 farmers participated in the study but reliable yield data were obtained from 72 on-farm trials. Yield data (grain and haulm) were recorded and representative samples were taken by treatment and farm across the study districts.

2.4. Harvesting, sample collection and yield determination

At physiological maturity, plants from the entire treatment plot area were harvested manually and total above ground biomass yield was recorded for each plot. The harvested plants were threshed separately by treatment plot and grain yield was measured. The haulm weight was determined by subtracting weight of grain from weight of total above ground biomass. Representative samples of grain (150 g) and whole plant haulm composed of stems, leaf and pod husks (750 g) were collected into labelled sample bags for each plot.

2.5. Estimation of haulm dry matter yield and harvest index

Subsamples of haulm and grain were dried at 100°C for 12 h in a forced air oven to determine dry matter (DM) percentages. The grain and haulm dry matter yields (DMY) were calculated by multiplying the weight at harvest by the respective DM%. Dried seeds were counted and harvest index (HI) was calculated as a ratio of total grain yield to total above ground biomass yield.

2.6. Laboratory analysis of grain, haulm and soil samples

The chemical composition of haulm and grain samples were analyzed at the Animal Nutrition Laboratory of the International Livestock research Institute, Addis Ababa. The samples used for analysis were dried at 65°C for 48 h and ground to 1 mm mesh size. Near infrared reflectance spectroscopy (NIRS) prediction was employed for the analysis of both grain and haulm samples using equations calibrated and validated for each crop. The NIRS instrument used was a FOSS Forage Analyzer 5000 with software package WinISI II. Predicted traits were ash, N, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and in vitro organic matter digestibility (IVOMD).

The soil samples were air dried, crushed, and passed through a 2 mm sieve for analysis of pH, cation exchange capacity (CEC), total N, available P and exchangeable cations. All soil analyses were carried out at the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, following standard laboratory procedures: suspension method for pH (1:1 soil to H2O), Kjeldahl method for total N, Mehlich method for available P, Walkley Black method for organic C and ammonium acetate method for exchangeable cations (Na, K, Ca and Mg) and CEC (IITA, 1982).

2.7. Statistical analysis

Homogeneity of data was checked in Minitab software using Levene’s test prior to actual analysis of the variance. Then, combined analyses of variance over locations was performed using general linear model (GLM) procedure of SAS 9.1 (SAS Institute Inc., 2004). Probability value of < 0.05 was used to declare significant effects of the treatment. In case of significant difference in means, Duncan multiple range test was used to locate mean separation.

3. Results

3.1. Soil property, grain yield, haulm yield and harvest index

Most of the sampled farms had low level of N and available P, with few exceptions where there was moderate and high level of available P (Table 2). While the variability in N content of the soil among farms remained relatively low (2.5 fold between the min. and max.), the difference in available P was found to be large (18 fold). The majority of the soils were acidic, with some of the farms tending to be alkaline. The CEC was generally moderate for the majority of the soils. Except for faba bean, grain yield increased significantly (P < 0.05) due to the combined application of P fertilizer and rhizobium inoculant compared to the control. Chickpea showed an increase in grain yield of 42%, common bean 23% and soybean 46% (Table 3). The treatments with either P application or rhizobium inoculation resulted in intermediate grain yields. Haulm DM yields significantly increased (P < 0.05) by 27% for faba bean and 45% for soybean due to +P +I treatments compared to the control. With regard to common bean, the haulm yield showed a different pattern, as the difference between +P +I and treatment and the control (14%) remained insignificant (P > 0.05), whereas that between +P +I and either -P +I or +P –I were significant (P < 0.05). Chickpea haulm DM yield was found to be similar between the treatments and the control. Harvest indices increased (P < 0.05) by 15% for chickpea and by 6% for common bean compared to the control. On the other hand, the HI of faba bean and soybean remained similar between the treatment and the control groups.

Exploration of the soil variables for possible influence on growth and yield of the legume crops revealed no statistically significant relationships. This might be attributed to the extreme variability of the values on soil parameters across locations. However, absolute responses
were observed due to the inoculation and P fertilizer treatments at the lower level of soil N (%). For instance, at 38% of the on-farm trials with below 0.19% soil N, average grain yield responses of 500 kg ha\(^{-1}\), 230 kg ha\(^{-1}\) and 864 kg ha\(^{-1}\) were obtained with inoculation, P fertilizer and combined application of both inputs respectively. In addition, negative relationships were noted between available soil P and pH of the soil which was reflected on grain yields. The low soil P availability could be associated with the acidic nature of the soils, especially at the soybean- and faba bean-trial sites. This might also be attributed to P fixation and reduced availability of P within these soils.

3.2. Nutritional value of the haulms

The quality of faba bean haulm was significantly improved (\(P < 0.05\)) as a result of the combined application of P fertilizer and rhizobium inoculant, with 24% increase in CP, 9% increase in IVOMD and 8% decrease in cell wall fractions (NDF and ADF) (Table 4). Chickpea haulm saw a 31% increase in CP (\(P < 0.05\)) and a 4% increase in IVOMD (\(P < 0.05\)) over the control. However, the ash and cell wall fractions of chickpea haulm were not affected by the treatments. On the other hand, common bean haulm showed significant (\(P < 0.05\)) improvement in all quality variables measured, with 11% increase in ash content, 26% increase in CP, 4% decrease in cell wall fractions and 3% increase in IVOMD over the control. Generally, treatments involving either P fertilizer or rhizobium inoculum appeared to be intermediate in terms of improving the chemical composition and IVOMD of the four haulm types.

3.3. Seed quality of the legume grains

Common bean grain showed improvement (\(P < 0.05\)) in all the three quality variables as a result of P application and rhizobium inoculation, with 6% increase in thousand seed weight, 2.2% increase in CP and 1.5% increase in IVOMD (Table 5). Soybean grain was also

### Table 2

Results of soil nutrient analysis for samples collected from farms in the study districts.

| District       | n  | pH (H2O) (1:1) | OC (%) | N (%) | P Meh (ppm) | Ca (cmol+ /kg) | Mg (cmol+ /kg) | K (cmol+ /kg) | CEC (cmol+ /kg) |
|----------------|----|----------------|--------|-------|-------------|---------------|---------------|--------------|----------------|
| Ada’a          | 9  | 7.42           | 1.19   | 0.12  | 10.3        | 28.3          | 4.27          | 0.82         | 28.3           |
| Agarga         | 3  | 5.60           | 2.37   | 0.31  | 6.17        | 19.5          | 3.24          | 0.63         | 19.5           |
| Bako Tibe      | 3  | 5.03           | 1.88   | 0.23  | 1.94        | 10.4          | 1.93*         | 0.40         | 10.4           |
| Boricha        | 5  | 5.60           | 1.67   | 0.18  | 22.6        | 12.2          | 1.37          | 1.35         | 12.2           |
| Damot Gale     | 10 | 6.93           | 2.05   | 0.26  | 36.2        | 25.5          | 2.98          | 2.83         | 25.5           |
| Dibatie        | 5  | 6.02           | 2.02   | 0.20  | 21.6        | 26.8          | 5.60          | 0.20         | 26.8           |
| Farta          | 3  | 5.17           | 1.36   | 0.16  | 3.58        | 13.9          | 2.17          | 0.20         | 13.9           |
| Gimbiuchu      | 9  | 7.54           | 1.04   | 0.12  | 9.84        | 23.0          | 2.28          | 0.57         | 23.0           |
| Ginir          | 6  | 7.02           | 1.54   | 0.18  | 4.60        | 26.2          | 3.54          | 0.85         | 26.3           |
| Halaba         | 5  | 6.04           | 1.20   | 0.14  | 23.9        | 11.5          | 1.31          | 1.82         | 11.5           |
| Pawe           | 4  | 5.93           | 2.14   | 0.20  | 2.59        | 17.7          | 5.25          | 0.42         | 17.7           |
| Shalla         | 10 | 6.31           | 1.70   | 0.19  | 16.1        | 13.1          | 1.16          | 0.96         | 13.1           |
| Sinana         | 4  | 6.80           | 1.74   | 0.20  | 8.48        | 34.9          | 3.90          | 1.69         | 34.9           |
| Soddo Zuria    | 3  | 5.37           | 1.48   | 0.19  | 9.31        | 8.24          | 1.06          | 0.98         | 8.24           |
| Yilmana Densa  | 5  | 5.14           | 1.69   | 0.22  | 2.94        | 17.8          | 3.86          | 0.69         | 17.8           |
| Tiroaleta      | 4  | 5.33           | 1.95   | 0.23  | 9.96        | 12.0          | 1.94          | 0.61         | 12.0           |
| Max            | 5  | 7.54           | 2.37   | 0.31  | 36.2        | 34.9          | 5.6           | 2.8          | 34.9           |
| Min            | 5  | 5.03           | 1.04   | 0.12  | 1.94        | 8.24          | 1.06          | 0.20         | 8.24           |
| Mean           | 6.08| 1.69           | 0.20  | 11.9   | 18.8        | 2.9           | 0.9           | 18.8         |                |

OC = organic carbon; P Meh = Phosphorous – Mehlich; CEC = cation exchange capacity.

### Table 3

Mean grain yield, haulm dry matter yield and harvest index of faba bean (n = 16), chickpea (n = 16), common bean (n = 24) and soybean (n = 16) as affected by phosphorus fertilizer and/or rhizobium inoculation across locations.

| Crop        | Variable          | Treatments | SEM  | \(P\)-value |
|-------------|-------------------|------------|------|-------------|
|             |                   | −P−I +P−I | −P +I | +P +I       |
| Faba bean   | Grain yield (t/ha)| 2.65ab    | 2.84a | 2.55b       |
|             | Haulm yield (t/ha)| 2.85b     | 2.95b | 3.00b       |
|             | Harvest index     | 0.46      | 0.46  | 0.44        |
| Chickpea    | Grain yield (t/ha)| 1.50b     | 1.65b | 1.98b       |
|             | Haulm yield (t/ha)| 2.25      | 2.3   | 2.47        |
|             | Harvest index     | 0.40b     | 0.40b | 0.42        |
| Common bean | Grain yield (t/ha)| 1.60b     | 1.74ab| 1.80ab      |
|             | Haulm yield (t/ha)| 1.62ab    | 1.54b | 1.55b       |
|             | Harvest index     | 0.47b     | 0.52b | 0.51b       |
| Soybean     | Grain yield (t/ha)| 1.75b     | 2.10ab| 2.46c       |
|             | Haulm yield (t/ha)| 2.12b     | 2.32  | 3.23b       |
|             | Harvest index     | 0.50      | 0.52  | 0.48        |

\(a,b\) Mean values with different letters of superscript within the rows are significantly different (\(P < 0.05\)), \(+P+I= \) phosphorus fertilizer with inoculation; \(−P−I= \) inoculation only; \(+P−I= \) phosphorus fertilizer only; \(−P+I= \) control; ns = not significant.
respond to the treatments for all the variables considered. However, chickpea grain did not positively affect (P < 0.01) by the treatments for two of the three variables measured resulting in a 9% increase in CP content and 6% increase in IVOMD over the control. However, chickpea grain did not respond to the treatments for all the variables considered.

### Table 4

Mean haulm nutritional value of faba bean (n = 16), chickpea (n = 16), common bean (n = 24) and soybean (n = 16) as affected by rhizobium inoculation and/or P fertilizer application across locations.

| Crop                | Variables | Treatments | P value |
|---------------------|-----------|------------|---------|
|                     |           | −P−I | +P−I | −P+I | +P+I | SEM |          |
| Faba bean           | % DM      |       |      |      |      |     |          |
| Ash                 | 6.91      | 7.78  | 7.67 | 7.64 | 0.399 | ns  |          |
| CP                  | 5.29b     | 6.38a | 6.45a | 6.52a | 0.244 | *   |          |
| NDF                 | 70.5b     | 64.8a | 64.9a | 74.9b | 1.42  | *   |          |
| IVOMD               | 42.9b     | 46.7a | 46.4a | 46.9a | 0.82  | *   |          |
| Chickpea            |           |       |      |      |      |     |          |
| Ash                 | 6.73      | 6.58  | 6.91 | 6.78 | 0.143 | ns  |          |
| CP                  | 3.31c     | 3.60a | 3.66b | 4.32b | 0.207 | *** |          |
| NDF                 | 63.2      | 63.5  | 62.9 | 62.1 | 0.46  | ns  |          |
| ADF                 | 50.8      | 50.8  | 50.5 | 49.2 | 0.41  | ns  |          |
| IVOMD               | 45.9b     | 45.8a | 46.5ab | 47.7a | 0.31  | **  |          |
| Common bean         |           |       |      |      |      |     |          |
| Ash                 | 7.63b     | 7.82a | 8.01ab | 8.50a | 0.19  | *   |          |
| CP                  | 5.94a     | 6.72a | 6.85a | 7.50a | 0.25  | **  |          |
| NDF                 | 69.8b     | 69.9a | 69.0ab | 67.8b | 0.52  | ns  |          |
| ADF                 | 56.9b     | 57.2a | 56.1ab | 54.9ab | 0.47  | *   |          |
| IVOMD               | 55.7b     | 55.8a | 56.8ab | 57.8ab | 0.49  | *   |          |
| Soybean             |           |       |      |      |      |     |          |
| Ash                 | 6.06      | 5.73  | 5.87 | 6.06 | 0.187 | ns  |          |
| CP                  | 4.67b     | 5.39b | 6.08a | 4.67b | 0.327 | *** |          |
| NDF                 | 76.4b     | 75.5a | 75.3ab | 76.4a | 0.77  | *   |          |
| ADF                 | 59.8b     | 57.9b | 57.9b | 59.8b | 0.82  | *   |          |
| IVOMD               | 49.6b     | 49.4a | 50.2ab | 49.6b | 0.45  | *   |          |

### Table 5

Mean thousand seed weight (TSW), crude protein (CP) and in vitro organic matter digestibility of chickpea (n = 16), common bean (n = 24) and soybean (n = 16) as affected by rhizobium inoculation and/or P fertilizer application across locations.

| Crop                | Variables | Treatments | P value |
|---------------------|-----------|------------|---------|
|                     |           | −P−I | +P−I | −P+I | +P+I | SEM |          |
| Chickpea            | TSW (g)   | 278   | 281  | 284  | 284  | 4.8 | ns  |
| CP (% DM)           | 19.8      | 19.8  | 19.7 | 20.2 | 0.21 | ns  | |
| IVOMD (%)           | 71.9      | 72.0  | 71.8 | 72.1 | 0.18 | ns  | |
| Common bean         | TSW (g)   | 199a  | 207b  | 204bc | 211b | 3.4 | ** |
| CP (% DM)           | 26.9      | 27.8  | 26.8  | 27.5b | 0.61 | *  | |
| IVOMD (%)           | 82.4      | 82.6a | 82.3  | 83.2  | 0.44 | *  | |
| Soybean             | TSW (gm)  | 137   | 146   | 146  | 143  | 2.6 | ns  |
| CP (% DM)           | 39.3b     | 40.7b | 43.1a | 42.9a | 0.5  | ** | |
| IVOMD (%)           | 73.4      | 75.1b | 78.3  | 78.1  | 0.62 | ** | |

### Table 6

Nitrogen uptake (kg/ha) by the grain legumes as affected by rhizobium inoculation and/or P fertilizer application across locations.

| Crop                | Variables | Treatments | P value |
|---------------------|-----------|------------|---------|
|                     |           | −P−I | +P−I | −P+I | +P+I | SEM |          |
| Chickpea            | Haulm N (kg/ha) | 11.9d | 13.2b | 14.5a | 16.9a | *  |          |
| Grain N (kg/ha)     | 47.5c     | 52.5a | 62.4ab | 68.8a | *  |          |
| N HI                | 0.80      | 0.80  | 0.81  | 0.80  | ns  |          |
| Common bean         | Haulm N (kg/ha) | 15.4b | 16.6a | 17.0b | 22.1a | ** |          |
| Grain N (kg/ha)     | 68.9b     | 77.4a | 77.2a | 87.1a | *  |          |
| N HI                | 0.62      | 0.82  | 0.82  | 0.80  | ns  |          |
| Soybean             | Haulm N (kg/ha) | 15.8b | 19.7a | 31.4a | 33.1a | *** |          |
| Grain N (kg/ha)     | 110b      | 137a  | 170a  | 176a  | *** |          |
| N HI                | 0.87      | 0.87  | 0.84  | 0.84  | ns  |          |

### 3.4. Effects of treatments on N uptake by the legumes

The N uptake in the grain and the haulm consistently improved with the fertilizer treatments (Table 6). On average, the N uptake due to inoculation and P application increased by 65% (P < 0.05) in the haulm and by 44% (P < 0.05) in the grain over the control. Out of the three grain legumes, soybean showed the highest response in N uptake, with 106% in the haulm and 60% in the grain. Despite increases in N uptake, the N harvest index (the ratio of N in the grain to total N uptake) remained similar across the treatments and the control.

### 4. Discussion

Low soil fertility has long been identified as a major constraint leading to high yield gaps (Tamene et al., 2017). The soil nutrient analysis results in the present study also indicate that the soils are too low in N and P to support optimal crop growth (Hazelton and Murphy, 2007). In this respect, legumes play a vital role in smallholder systems due to N input into the soil through biological atmospheric N₂ fixation. The overall efficiency of atmospheric N₂ fixation is determined with the presence of effective soil rhizobium bacteria population and plant available P. Although numerous reports showed the positive effects of rhizobium inoculation and P fertilizer on grain yield of legumes, few studies have investigated as to how this agronomic practice affects fodder traits of the legumes, which in turn affects the crop-livestock system. This study involved on-farm trials across diverse agroecologies and soil types to generate practical evidence on the effects of rhizobium inoculation and P fertilizer application on yield and nutritive values of grain and haulm of faba bean, chickpea, common bean and soybean.

### 4.1. Effects of rhizobium inoculation and P fertilizer on yield variables

The increased grain yield in the present study agrees with earlier findings where a yield increase ranging from 16 to 100% has been reported due to rhizobium inoculation and P application (Ibsa, 2013; Tagore et al., 2013; Wolde-meskel et al., 2018). The average grain yield improvement in the present study (30%) appears to be considerable in view of its potential to increase land productivity with limited capital inputs in the smallholder system. Moreover, the significant improvement in haulm DM yield of all the studied crops (except chickpea) shows that the treatments favored whole plant growth, which translates into higher haulm yield. In earlier reports, chickpea responded positively in terms of haulm DM yield due to the application of similar treatments (Tagore et al., 2013). Lack of significant difference in chickpea haulm yield in the present observation might be attributed to the leaf shedding nature of the crop at maturity. Biomass yield
measurement toward the end of the vegetative stage would provide the true response of chickpea to the treatments in haulm yield. Generally, in the present experiment, the application of P fertilizer and seed inoculation with effective rhizobium strains have positively affected the nodulation and vegetative growth of the plants, which ultimately resulted in increased yield performance.

4.2. Effect of rhizobium inoculation and P fertilizer on nutritional value of the haulm

The present study showed that all nutritional quality indicators of the legume haulms were significantly affected by the treatments (Table 2). This result appears to be consistent with published reports (Habbasha et al., 2007; Ibaa, 2013; Tagore et al., 2013). In the present study, the CP content was increased in haulms by 25% in faba bean, 31% in chickpea, 26% in common bean and 44% in soybean over the control as a result of the combined application of rhizobium inoculation and P fertilizer. The improvement in CP content was associated with a decrease in cell wall fractions, which shows an improvement in overall nutritional quality. This was evident from the consistent improvement in IVOMD from 1% in soybean haulm to 4% in faba bean haulm (Table 4). Earlier assessments have indicated that a 1% increase in digestibility of crop residues would result in an increase in animal performance (milk, meat and draft power outputs) in the range of 6–8% (Kristjanson and Zerbini, 1999). Theoretically, this means the improvement in haulm nutritive value in the present study can be translated to 6–24% increase in animal performance in the smallholder systems. Given the importance of livestock in the crop-livestock system and the role of crop residues as livestock feed (Duncan et al., 2016) application of soil fertility treatments tested in this study appear very important to enhance both crop and livestock productivity. In addition to the treatment effects, inherent differences between the grain legumes in haulm nutritive quality traits were visible. For instance, soybean haulm on average showed a 2–3% increase in IVOMD compared to the other legumes. These quality and yield differences would be used as input in deciding which crop and type of management to apply in the context of mixed crop-livestock systems.

4.3. Effects of rhizobium inoculation and P fertilizer on grain quality variables

The present study indicated that in addition to positive effects on grain yield, there was a significant improvement on grain quality in terms of thousand seed weight, CP and IVOMD for common bean and soybean, although chickpea grain remained unaffected by the treatments. This has an important economic significance as the treatments improved grain yield in all crops and increased IVOMD (Table 4). Earlier assessments have indicated that a 1% increase in digestibility of crop residues would result in an increase in animal performance (milk, meat and draft power outputs) in the range of 6–8% (Kristjanson and Zerbini, 1999). Theoretically, this means the improvement in haulm nutritive value in the present study can be translated to 6–24% increase in animal performance in the smallholder systems. Given the importance of livestock in the crop-livestock system and the role of crop residues as livestock feed (Duncan et al., 2016) application of soil fertility treatments tested in this study appear very important to enhance both crop and livestock productivity. In addition to the treatment effects, inherent differences between the grain legumes in haulm nutritive quality traits were visible. For instance, soybean haulm on average showed a 2–3% increase in IVOMD compared to the other legumes. These quality and yield differences would be used as input in deciding which crop and type of management to apply in the context of mixed crop-livestock systems.

5. Conclusion

Rhizobium inoculation and P fertilizer significantly improved grain yield in all crops and haulm yield of all crops except chickpea. The soil fertility treatments also improved the protein content of the haulm, reduced the cell wall fractions and increased IVOMD. Similarly, except in chickpea, the treatments enhanced food values of the grains by improving the CP and IVOMD. The results show that rhizobium inoculation and P fertilizer can be used to enhance the whole plant value of grain legumes in smallholder mixed crop-livestock systems.

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