Grain yield and protein content of upland rice (*Oryza sativa* L.) varieties as influenced by combined application of primary secondary and micronutrients under Nitisols

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Field experiment was conducted on Nitisols to evaluate the effects of combined application of primary, secondary and micronutrients on grain yield and protein content of upland rice varieties compared to the national recommendation. Factorial combination of five nutrient combinations (control, NP, NPK, NPKSZn and NPKSCaZn) and three upland rice varieties (Nechu Eruze, Superica-1 and NERICA-4) were laid out in a randomized complete block design with three replications. The result revealed that nutrient combinations significantly affected plant height and number of effective tillers m⁻². The highest grain number per panicles of 122 and 1000 grain weights of 30.9 g were recorded from NPKSZn. The maximum grain yield (4055.6 kg ha⁻¹) was also obtained from NPKSZn, followed by NPKSCaZn. Moreover, maximum grain protein content was registered from NPKSZn and NPKSCaZn. In contrast, the lowest value of these parameters was scored from the control. Among the varieties, NERICA-4 performed better than both varieties in yield and yield components. However, grain protein content of rice varieties was statistically similar. Overall, combined application of primary, secondary and micronutrients significantly improved grain yield and protein content of upland rice compared to nationally recommended NP combinations.

**Key words:** Nechu Eruze, NERICA-4, Nitisols, nutritional security, rice grain yield, Superica-1.

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population, providing over 20% of the total calorie and 15% of the protein that human needs (Seck et al., 2012). It is the most promptly growing source of food in Africa, and is of noteworthy importance to food security in an increasing number of low-income food-deficit countries (FAO, 2015). In sub-Saharan Africa (SSA), rice is currently one of the rapidly growing food...
crops in production and consumption (Kinfe et al., 2017). Cultivated area in SSA is reaching 10 million hectares with annual production of about 23 million tons and average per capita consumption of 24 kg per year (FAO, 2015). Upland rice is one of the main staple food crops in inter-tropical highland areas and much of the future expansion of the world’s rice varieties depends on it (Negussie et al., 2008). Further, about 14 million hectares of land is dedicated to upland rice, accounting for 4% of global rice production (Kinfe et al., 2017).

In Ethiopia, rice is among the target strategic commodities that have received great focus and is considered as the “millennium crop” that is expected to contribute in ensuring food security in the country and it plays a critical role in nutritional security (Mekonnen et al., 2017). The total rice area coverage in Ethiopia including upland rice in 2016 was estimated at 48,418 ha with average annual production and productivity of 136,000 tones and 2.9 t ha⁻¹, respectively (CSA, 2017). This however, is much lower than the world’s average rice yield of 4.64 t ha⁻¹ (FAOSTAT, 2017).

Soil nutrient depletion and shortage of adapted varieties are among the major constraints for the yield gap. The gap was further increased due to lower use of external inputs that led to negative nutrient balances in the soil (Rhodes et al., 1996). Kumar and Yavdav (2005) related the decline in productivity of rice with continuous cropping to deficiency of primary, secondary and micronutrients mainly N, P, K, S, Zn and imbalanced nutrition. In Southern Ethiopian, Nitisols are among the most extensive agricultural soils though, soil degradation threatens their productive (Eyasu, 2017) and nutrient balances at field level for Nitisols were found to be -102, -45 and -67 kg ha⁻¹ for NPK, respectively (Elias, 2002). Moreover, Ethiopian Soil Information Service (2013) reported that most arable lands in Ethiopia including the study area are deficient with secondary and micronutrients in addition to the lower level of primary macronutrients (NPK). Potentially, these limit rice production, despite continued use of only NP nutrient combination as blanket recommendation over decades (Abebe et al., 2020). Sillanpaa (1982) identified micronutrient deficiencies for selected cereals in Ethiopia, and highlighted the need for micronutrient supply especially Zn to address observed deficiencies and to realize full potential in crop productivity. Crop response to secondary and micronutrients such as S and Zn has been reported (Abebe et al., 2020; Demiss et al., 2019).

Despite the importance of secondary and micronutrients in enhancing crop productivity, they are hardly studied in Ethiopia. In the country, the main focus has been on primary macronutrients, that is NPK but there is emerging, though, scattered evidence of crop productivity being limited by secondary and micronutrients (Kihara et al., 2017). On the other hand, balanced supply of macro and micronutrients has a paramount importance and may guarantee optimal crop production, better food quality and benefit smallholder farmers. Therefore, information is required to identify nutrients that limit rice production which could be used for fertilizer blending to produce blends of the right formulation (Kaizzi et al., 2018). However, little if any has been done on the impact of combined application of primary, secondary and micronutrient except nitrogen and phosphorous on rice productivity in Ethiopia. Owing to the above facts, this study was designed to evaluate the effect of combined application of primary secondary and micronutrients on grain yield and protein content of upland rice varieties compared to the national recommendation.

MATERIALS AND METHODS

Description of the study area

Field experiment was conducted at Guraferda District of Bench-Maji Zone, Southern Nations, Nationalities and Peoples’ Regional State, Ethiopia. The experiment was undertaken during 2015 main cropping season. The district lies between altitudes of about 850 and 1995 m above sea level. The annual rainfall pattern is unimodal with rainy season from mid-March to mid-November (Kassa et al., 2017). The average annual temperature and rainfall ranges from 25 to 39°C and 1200 to 1332 mm, respectively (Weldegebriel, 2015). The predominant soil type in the study area is Nitisols (FAO, 2001); primary, secondary and micronutrients; N, P, K, S and Zn, were deficient in the soil (ATA, 2016). The soil was relatively highly weathered well drained, clay in texture and strongly to moderately acidic in reaction.

Treatments, experimental design and procedure

Factorial combination of 5 nutrient combinations, that is control without fertilization (control), nationally recommended NP, NPK, NPKSzn and NPKSCaZn and 3 rice varieties (Nechu Eruze, Superica-1 and NERICA-4) were laid out in Randomized Complete Block Design (RCBD). NERICA 4 and Superica-1 are popular and typical upland rice varieties in Ethiopia, and dominantly produced by private companies in the study area; Nechu Eruze is a local variety produced by most small holder framers. Treatment combinations were replicated 3 times. Each replication had 15 plots corresponding to the 15 treatment combinations. A uniform size of 4 m x 2.5 m (10 m²) was used for each plot. The plot size accommodated 16 rows at the spacing of 25 cm between rows. A 1 m wide-open strip separated the blocks, whereas the plots within a block were 0.5 m apart from each other. The experimental field was ploughed and leveled properly before planting. The required agronomic practices were followed uniformly in all plots throughout the growing period.

N and P in the NP and NPK combinations were applied in the form of DAP fertilizer; whereas these two primary macronutrients were supplied in the form of NPS (19N-38P₂O₅-7S) fertilizer for NPKSzn and NPKSCaZn combinations. The remaining two secondary macronutrients and the micronutrient; K, Ca+² and Zn+², were applied in the form of KCl (60 K₂O), CaCO₃ and ZnSO₄ (23 Zn and 10 S), respectively. Urea to all fertilizer combinations and TSP to NPKSzn and NPKSCaZn combinations were applied in order to make N and P of the nutrient combinations equal to the recommended level. All nutrient sources except urea were applied at sowing. However, since the N content of DAP and NPS was not equal, the difference was applied to DAP at planting as urea to
balance the N content between the nutrient combinations. The remaining N was applied in split in the form of urea. Detail of nutrient compositions is presented in Table 1. Days to 50% emergence, flowering and physiological maturity were collected at plot level. Plant height (cm) was recorded from the two outer rows excluding the border and central rows. Whereas, total number of grain panicles \(^{-1}\), number of effective tillers per meter square, thousand seeds weight (g) and grain yield (kg ha\(^{-1}\)) were recorded from the central rows.

### Grain protein analysis

Grain samples collected at harvest were dried for the determinations of N concentrations in grain. The grain samples were grounded and sieved through 0.5 mm size sieve and were saved for laboratory analysis. Nitrogen in the grain was analyzed by wet-oxidation procedure of the modified Kjeldahl method (Nelson and Sommers, 1973). Grain protein content (GPC) (%) was determined by multiplying total N with 5.75 (Brahmanand et al., 2009).

### Soil sampling, sample preparation and analysis

Thirty sub-samples using random sampling technique were collected from the study area at a depth of 0-20 cm and a composite was made before planting; it was analyzed for particle size distribution, \(pH_{\text{HCO}_3}\), soil organic carbon, available N, P, K, S, CEC, exchangeable bases and micronutrients following standard procedures.

### Statistical analysis

Data were subjected to the analysis of variance (ANOVA) using statistical analysis systems (SAS Version 9.1.3) (SAS, 2003). Whenever significant differences were detected in the F-test, the means were compared using the least significance difference (LSD) test at 5% levels of significance.

### RESULTS AND DISCUSSION

#### Soil physical and chemical characteristics

Results of the composite soil analysis of the study areas before planting indicated that textural classes of the surface soil were clay (Table 2). The soil was found to be moderately acidic in reaction with a pH of 5.6 as per the rating of Tekalign (1991). According to Landon (2014), organic carbon and total nitrogen contents of the soils were in a low range. On the other hands, available phosphorus contents were in a very low range as stated by Olsen and Sommers (1982). Cation exchange capacity (CEC) was medium according to the rating of Landon (2014). Moreover, available S content of the soil was low according to Havlin et al. (2014). The result is in line with the finding of Abebe et al. (2020) who reported low S content in Nitisol of Central Ethiopia. Exchangeable Ca and Mg were the dominant cations in the soil sample. Concentrations of exchangeable cations were generally in the order of Ca > Mg > K > Na. Cation exchange capacities (CEC) of the studied soils were rated as high according to the rating of Landon (2014). In contrast to available Zn which is deficient in the soil, available Fe, Mn and Cu were sufficient. This is in agreement with the finding of Abebe et al. (2020).

#### Days to 50% emergence, flowering and days to physiological maturity

None of the nutrient combinations, varieties or their interaction influenced crop emergence and date to 50%
flourishing significantly. Favorable moisture condition due to uniform rainfall distribution during planting might contribute to smooth and even germination of rice on similar dates. Uniform germination of rice and wheat was also reported under different levels of N fertilizer (Yesuf and Worku, 2018) and varieties (Melesse, 2007), respectively.

Nutrient combinations had a significant (p < 0.05) effect on mean days to physiological maturity of rice. The result revealed that the highest delay was observed in NP combination, which delayed 8 days as compared to the control (Table 3). However, this was not significantly different from treatments that received NPKSzN, NPKScaZn and NPK. Delayed physiological maturity with N containing fertilizers might be attributed to higher uptake of N fertilizer in the straw that encouraged excessive vegetative growth resulting in delayed maturity. Similarly, Brady and Weil (2002) reported that compared to unfertilized plants, application of N delayed plant maturity. Moreover, WARDA (2008) reported that application of N to NERICA variety delayed maturity as compared to the control; this is in agreement with our result.

Days to physiological maturity was also significantly (p < 0.05) varied among rice varieties. However, the interaction effects of nutrient combinations and varieties had no significant effect on days to physiological maturity. Maturity of NERICA-4 was significantly delayed by 3 days compared with Superica-1 (Table 3). Differences in maturity can be caused by the difference in the genetic makeup of the varieties (Bhuiyan et al., 2014). It might also be due to the agronomic characteristics and to the climate adaptability of different rice varieties to the local condition (Romualdo and Jesusa, 2014). Difference in days to physiological maturity among rice varieties has also been reported (Tefera et al., 2019).

Table 3. Effect of variety and nutrient combinations on days to 50% emergence, flowering and physiological maturity.

| Treatments | 50% emergence | 50% flowering | DTPM | PH (cm) | NET/m2 |
|------------|---------------|---------------|------|--------|--------|
| Nutrient combinations | | | | | |
| Control    | 7.1           | 64.5          | 97b  | 74.0c  | 166.6c |
| NP         | 7.0           | 65.0          | 105a | 78.0b  | 235.9b |
| NPKSzn     | 7.1           | 65.0          | 103a | 87.0a  | 279.9a |
| NPKScaZn   | 7.0           | 66.5          | 103a | 85.0a  | 249.3b |
| NPK        | 7.0           | 65.8          | 103a | 80.8b  | 244.3b |
| LSD 5%     | NS            | NS            | 3.4  | 3.8    | 28.6   |
| Varieties  | | | | | |
| NERICA-4   | 7.1           | 63.0          | 104a | 77b    | 260.3a |
| Superica-1 | 7.1           | 62.9          | 101b | 90a    | 226.8b |
| Nechu Eruze| 7.0           | 63.1          | 103b | 75b    | 218.5b |
| LSD 5%     | NS            | NS            | 2.6  | 3.0    | 22.1   |
| CV (%)     | 7.5           | 9.0           | 3.4  | 5.0    | 12.6   |

Means followed by the same letter in the same column are not significantly different at p < 0.05 probability level, NS: Not significantly DTPM: Days to physiological maturity, PH: Plant height NET/m2: Number of effective tiller per meter square

Plant height

Combined application of primary secondary and micronutrients significantly increased plant height compared to the recommended NP. The recommended NP combinations also significantly increased plant height over the control. The lowest mean plant heights of rice (74 cm) was recorded at control treatments, while a maximum height of 87 cm was recorded from the application of NPKSZn; however, this result was statistically at par with the height of rice crop obtained from the application of NPKScaZn (85 cm). Omission of secondary and micronutrients from NPKSzn and NPKScaZn application significantly reduced plant height by 6.2 and 4.2 over NPK fertilizer (Table 3). This result contradicts the finding of Abebe et al. (2020) who reported a reduction in plant height with the omission of Zn. However, the result is in agreement with Sudha and Stalin (2015) and Singh et al. (2012) who reported a significant reduction in plant height of upland rice with omission of S and Zn from fertilizer schedule. Furthermore, Chimdessa (2016) reported that application of NPKSBZn blended fertilizer increased plant height of maize by 16 and 111 cm over the recommended NP fertilizer and the control respectively in Western Ethiopia. The same source attributes the increment in plant height with combined application of primary, secondary and micronutrients to increase in cell elongation and more vegetative growth due to different nutrient contents of the fertilizer: NPKS and micronutrients (Chimdessa, 2016). An increase in plant height might also be attributed to the adequate supply of zinc that contributed to accelerate the enzymatic activity and auxin metabolism in plants (Fayez and Khan, 2016).

Varieties also had a significant effect on mean plant height of rice. The maximum plant height of 90 cm was
Table 4. Effect of nutrient combinations and varieties on number of grain per panicle, thousand grain weights and grain yield of rice.

| Treatments         | NGPP    | TGW (g)  | GY (kg ha⁻¹) |
|--------------------|---------|----------|--------------|
| **Nutrient combinations** |         |          |              |
| Control            | 81.44a  | 25.96c   | 3157.20c     |
| NP                 | 95.00d  | 27.13bc  | 3577.80b     |
| NPKSZn             | 117.67a | 30.90a   | 4055.60a     |
| NPKSCaZn           | 115.00b | 28.89ab  | 4038.90a     |
| NPK                | 103.22c | 28.310bc | 3600.00b     |
| LSD 5%             | 10.8    | 2.51     | 409.63       |
| **Varieties**      |         |          |              |
| NERICA-4           | 105.53a | 30.66a   | 4098.30a     |
| Superica-1         | 101.60b | 27.13b   | 3806.70b     |
| Nechu Eruze        | 100.33b | 26.93b   | 3175.00b     |
| LSD 5%             | NS      | 1.9      | 318.37       |
| CV (%)             | 10.5    | 9.2      | 11.51        |

Means followed by the same letter in the same column are not significantly different at p < 0.05 probability level, NS: not significantly, NGPP: number of grain per panicle, TGW: thousand grain weight and GY: Grain yield.

recorded at variety Superica-1 while the minimum plant height of 75 cm was observed in the Nechu Eruze variety (Table 3). The difference in plant height could be attributed to the varietal characteristics of the crops planted (Tefera et al., 2019). Plant height is the end product of several genetically controlled factors mostly governed by the genetic make-up of the genotypes (Sadiqur et al., 2018). In line with our finding, significant variations in height among rice varieties were also reported by Delessa (2007) and Tefera et al. (2019). Interaction effects of nutrient combination and variety on mean plant height of rice was non-significant.

**Number of effective tillers**

Applying secondary and micronutrients in combination with primary macronutrients increased number of effective tillers. The highest number of effective tillers was recorded from the combination of S and Zn with NPK followed by NPKSCaZn. The lowest value of this parameter was obtained from the control. Compared to the control treatment, application of locally recommended NP nutrients increased number of effective tillers by 68.6% (Table 3). Similar result was reported by Ferdous et al. (2018). Increased effective tiller production of NPKSZn compared to the recommended NP and NPK can be attributed to the ability of Zn to increase N use efficiency and Zn induced enzymatic activity as well as auxin metabolism in plants (Arif et al., 2018; Rana and Kashif, 2014).

Number of effective tillers was also significantly different among the rice varieties. The highest value of this parameter was scored from NERICA-4 and the lowest value from Nechu Eruze variety that was statistically similar with the variety Superica-1 (Table 3). This might be due to different capacity of varieties in tiller production (Suleiman et al., 2014).

**Number of grain per panicles**

Nutrient combinations significantly increased (p < 0.01) number of grain per panicles. The main effect of varieties and its interaction with nutrient combinations did not show significant difference in mean number of grain per panicles. The highest number of grain per panicles (122) was recorded from the treatment that received NPKSZn followed by NPK application (111.3) which however was statistically at par with that obtained from NPKS CaZn (109). The lowest mean number of grain per panicles (84.9) was scored from the control treatment (Table 4). Compared to NP and NPK nutrient combinations, mean values of number of grain per panicles were increased by 22 and 10 % for the application of NPKSZn, respectively. In agreement with our finding, Chimdessa (2016) reported a significant increase in number of kernels per row through balanced nutrient supply including S and Zn. Moreover, the result of Singh et al. (2012) showed that number of grains per panicle of rice was significantly increased by 13 and 14 grains per panicle with the application of S and Zn over control. Higher grain production due to zinc might be attributed to its involvement in many metallic enzyme system, regulatory...
functions, and auxin production (Sachdev et al., 1988) enhanced synthesis of carbohydrates and their transport to the site of grain production (Pedda-Babu et al., 2007).

Thousand grain weight

Thousand grain weight of rice was significantly ($p \leq 0.01$) affected by the nutrient combinations. The highest 1000 grain weight of 30.9 g was recorded at a nutrient combination of NPKSZn, which however, was statistically similar with that recorded from the application of NPKSCaZn. In contrast, the lowest 1000 grain weight of 26 g was obtained from the control treatments (Table 4). Combined application of primary secondary and micronutrients resulted in the highest 1000 grain weight, which was significantly higher than the control, recommended NP and NPK combinations. The mean values of 1000 grain weight from the combination of primary, secondary and micronutrients (NPKSZn) increased by 14 and 9.2% as compared to the recommended NP and NPK fertilizers, respectively; while it increased by 19% as compared to control. The more grain weight of rice for NPKSZn in the present finding might be attributed to the positive interaction of nutrients in this treatment.

This result is in line with the finding of Chimdessa (2016) who reported that application of blended fertilizes significantly increased 1000 grain weight of maize by 220 g over the control. Similarly, Fayaz and Hamayoos (2016) observed that NPKZn combinations significantly increased 1000 grains weight of rice by 5 g over NPK alone. Moreover, a significant increase in 1000 grain weight of rice by 13.6% through S incorporation in NPKBZn combination was reported by (Dash et al., 2015).

The highest 1000 grain weight of rice from NPKSZn might also be attributed to an increase in availability of Zn in the soil solution. An increase in 1000 grains weight of rice up on Zn fertilization might also be due to its involvement in the carbonic anhydrase activity and more carbohydrate accumulation in the seeds (Sudha and Stalin, 2015). Furthermore, Cliquet et al. (1990) reported significant difference on grain yield through direct or indirect effects of K on other morphological and physiological parameters. In a similar scenario, Havlin et al. (2014) explained that K is involved in the working of more than 60 enzymes, in photosynthesis and the movement of its products (photosynthates) to storage organs (seeds, tubers, roots, and fruits). The result also revealed that 1000 grain weight of rice was significantly ($p < 0.00$) influenced by the main effect of variety. Despite this, its interaction with fertilizer treatments did not show significant difference in this parameter. The highest 1000 grain weight of 30.1 g was obtained from NERICA-4. In contrast, the lowest value of this parameter (26.9 g) was scored from Nechu Eruze that was statistically similar with that recorded from variety Superica-1 (26.9 g) (Table 4). Previous result also confirmed the present finding (Mayumi et al., 2017).

Grain yield

Primary, secondary and micronutrient combinations significant increased grain yield of rice. The omission of all macro and micro nutrients from the experimental plot drastically decreased yield than plots fertilized with complete treatments; NPKSZn and NPKSCaZn. The highest grain yield of 4055.6 kg ha$^{-1}$ was obtained from NPKSZn application that was statistically similar with that obtained from NPKSCaZn. In contrast, the lowest grain yield of rice was obtained from the control; all the other fertilization treatments performed in between. Compared to the recommended NP and NPK combinations mean grain yield was increased by 477.8 and 455.6 kg ha$^{-1}$ with the application of NPKSZn nutrients, respectively (Table 4). A similar result on upland rice was also reported (Kalizzi et al., 2018). Our result is also in agreement with the finding of Shah et al. (2008) who reported that long-term omission of major nutrient individually from the complete treatment (NPKSZn) significantly decreased rice yield and was significantly higher than control. Furthermore, the finding of Dash et al. (2015) showed that highest significant grain yield was recorded when rice received primary secondary and micronutrients (NPKSBZn) and yield decreased by 19.4–27% due to omission of NPK or PK and by 17.1–32.6% in absence of S and Zn individually or in combination. The lowest yield in control plots might be due to reduced vegetative development that resulted in lower radiation interception and, consequently, low efficiency in the conversion of solar radiation (Sallah et al., 1998). The increase in grain yield with the balanced nutrient supply which contained primary, secondary and micronutrients was an indicator of low soil fertility level in Guraferda District of Southwestern Ethiopia for rice production. Benti (1993) stated that, although adoption of new varieties is moving fast in Ethiopia, fertilizer management techniques need to supplement the existing potential of the varieties. This showed that low soil fertility is among the greatest constraints to crop production in Ethiopia (Kelsa et al., 1992). Grain yield increase with NPKSZn and NPKSCaZn which contained K indicated that there is a need to supplement the element for rice production. In this scenario, Fageria and Baligar (2005) reported that many soils of the tropical regions are unable to supply sufficient K to field crops. Hence, application of this element in adequate amount is essential for obtaining optimal crop yields. Many other researchers also have reported an increase in yield through potassium application (Grunes et al., 1998; Johns and Vimpany, 1999; Abebe et al., 2020). The increase in grain yield could be attributed to beneficial influence of yield contributing
Table 5. Main effect of variety and fertilizer type on crude protein content of the grain (%).

| Treatments         | Crud protein (%) |
|--------------------|------------------|
| Nutrient combinations |                 |
| Control            | 1.96<sup>c</sup> |
| NP                 | 2.17<sup>c</sup> |
| NPKSZn             | 2.77<sup>a</sup> |
| NPKSCaZn           | 2.57<sup>ab</sup>|
| NPK                | 2.43<sup>b</sup> |
| LSD 5%             | 0.218            |
| Varieties          |                  |
| NERICA-4           | 2.48             |
| Superica-1         | 2.35             |
| Nechu Eruze        | 2.31             |
| LSD 5%             | NA               |
| CV (%)             | 9.5              |

Means followed by the same letter in the same column are not significantly different at p < 0.05 probability level, NS: not significantly.

Characters and positive interaction of nutrients in the crop through the application of primary, secondary and micronutrients. Grain yield increase with NPKSZn compared to NPK highlighted the need to supplement S and Zn for rice production in the study area. A significant yield increase of rice with combined application of S and Zn was also reported (Singh et al., 2012). Grain yield of rice was also affected by the main effect of varieties. The highest grain yield of rice was obtained at variety NERICA-4, while the lowest value was obtained with variety Superica-1 followed by Nechu Eruze (Table 4). This confirmed the report of Tefera et al. (2019) and Islam et al. (2010) that varieties with longer growth duration usually produce more grain yield than the varieties with shorter growth duration. Further, the difference in yield among the varieties might also be attributed to the difference in the number of productive tillers, varietal yielding capabilities and also to the growth performance of every variety tested (Romualdo and Jesusa, 2014).

**Grain protein content**

Combined application of S and Zn with macronutrients increased grain protein of rice. The highest grain protein concentration of 2.77% was recorded at a nutrient combination of NPKSZn, which however was statistically similar with that recorded from the application of NPKSCaZn (2.57%). In contrast, the lowest grain protein was obtained from the control treatments (Table 5). Application of NPKSZn resulted in the highest grain protein content, which was significantly higher than the recommended NP and NPK fertilizer. The mean values of grain protein in NPKSZn increased by 41.3% as compared to control. The highest grain protein concentration from the combinations of primary, secondary and micronutrients might be attributed to the presence of N, S and Zn. This is also in agreement with the findings of Hakoomat et al. (2014) who reported that protein contents of rice grain were significantly improved by combined application of N and Zn application. Moreover, significant increase in grain protein content of rice with the application of S was also reported by Rahman et al. (2007). Rice protein is valuable as it has unique hypoallergenic properties and ranks high in nutritive quality (rich in the essential amino acid lysine) among the cereal proteins (Nasrollah and Seyed, 2014). Liu et al. (2008), in their research, showed a significant positive correlation between activities of protein synthesizing enzymes and absorption of nitrogen in grain. The highest protein content in Zn containing nutrient combination might also be due to the fact that application of Zn increased N-metabolism which enhanced accumulation of amino acids and drastically increased the rate of protein synthesis and consequently protein content in grain (Sudha and Stalin, 2015). The role of Zn in increasing protein might also be due to the fact that zinc application enhanced Zn concentration in the plant which might be associated with RNA and ribosome induction. The result accelerated protein synthesis (Keram et al., 2014).

**Conclusion**

Balanced nutrient supply based on limiting nutrients for a cereal crop improved yield and nutritional value of the grain. Combined application of primary, secondary and
micronutrients on upland rice showed a significant effect on grain yield and protein content in the study area. On the other hand, nationally recommended NPK combinations performed low compared to NPKSZn, indicating that rice production in the study area needs application of secondary and micronutrients in addition to primary nutrients. The result revealed maximum grain yield, 1000 grain weight, grain protein content, number of grain per panicle and number of effective tiller per m² from NPKSZn. Among the rice varieties, NERICA-4 performed better in all parameters. Therefore, to improve grain yield and protein content of rice in the study area combined application NPKSZn might be recommended. However, further research has to be done to get strong recommendations for fertilizers and varieties in the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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