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# Zinc management for higher productivity and profitability under diversified fodder maize based systems in semi-arid conditions

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**Abstract**

The experiments on Zn management in diversified fodder maize based system was conducted with the objective of enhancing cropping system productivity and profitability under irrigated conditions during 2016-17 and 2017-18. The higher green and dry fodder productivity of maize (African tall) under maize-mustard-wheat cropping system was observed. The B: C ratio of fodder maize was more than 1 and ranged between 1.57-1.68. Better growth, agronomic characters and yield were recorded with higher levels of Zn (5.0 kg/ha). Significantly higher production efficiency (744 and 186 kg/ha/day of green and dry fodder maize, respectively) was also recorded with 5.0 kg Zn/ha over no Zn (676 and 168.9 kg/ha/day of green and dry fodder, respectively). There was increase of almost 15% in net return under 2.5 and 5.0 kg/ha Zn applications over no Zn application. On residual Zn, early mustard variety, PM 28 invariably resulted in higher seed yield. Wheat (HD 3118), late sown cultivar produced higher seed yield with Zn solubilizer at residual 5.0 kg Zn/ha level. Onion yield increased with increase in Zn fertilization. Zn solubilizer (ZnS1) resulted in higher fodder maize productivity and profitability. NPK uptake (kg/ha) was comparatively higher in maize-mustard (PM 28)-wheat cropping system, and among the different primary elements, uptake of potash was maximum over P and N in fodder maize crop.

**Keywords:** B:C ratio, Crop diversification, Fodder maize, Late wheat, Zinc uptake

## Introduction

Crop diversification is the need of hour for enhancing productivity and maintaining sustainability in production system. Together with rice and wheat, maize constitutes a major chunk of area under food and fodder crops. It is the high time to diversify the cropping system to increase resilience of agricultural production system in the country. The diversification with need based crops with suitable varieties and their produce will bring the self-reliance in the location specific mode. Maize is one of the major cereal crops of the world. In India, it is the third most important crop after rice and wheat. The acreage, tonnage and productivity of maize crop were 9.9 Mha, 26.26 MT and 2.67 t/ha, respectively (Anonymous, 2018). The area under different fodder crops has been remained static of about 4% of cultivated area (approx. 6.0 Mha) over the years (Anonymous, 2019). Maize along with barley, sorghum and pearl millet account for about 44% of the in animal feed supply (IGFRI, 2015). Hence, maize with other prominent fodder crops as sorghum, berseem, lucerne, bajra, fodder cowpea and oats are being grown in more than 50% of the area under fodder crops (Choudhary *et al*., 2019; Roy *et al*., 2019). Due to decreasing size of operational holdings, diversified bio-intensive systems are need of the hour. Growing only fodder crops is becoming difficult as a viable farming option. Hence, fodder maize based diversifying agricultural production may be considered as a viable option due to its wider adaptability in multiple seasons in different ecologies. Being a multipurpose crop, maize is also in huge demand for animal fodder. The demand for quality fodder and its other industrial use encourages the farmers to grow maize intensively. At present, the country faces a net deficit of 61.1% green fodder, 21.9% dry crop residues and 64% concentrate feeds (Chaudhary *et al*., 2014; IGFRI, 2015; Roy *et al.,* 2019). To ensure supply of quality fodder for the ever increasing livestock population, there is a need for productivity enhancement of fodder crop based systems. In this regards, intensive fodder based diversified system can therefore, sustainably meet the increasing demand of feed and fodder on available limited resources. Due to heavy nutrient requirement by maize crop, over and under nutrient fertilization results in lesser yield than the genetic yield potential. During the last decade the production of maize increased significantly in India due to its increased area and productivity (IGFRI, 2015). Still, there exist huge yield gap mainly due to the incongruity between state recommendation and farmer's practice which is not only decreases the productivity but also causes nutrient mining.

Maize has great potential for higher productivity but it is also an exhaustive crop for nutrient demand. There exist a vicious cycle, as the imbalanced nutrient supply to the crops, often led to low productivity, which in turn also responsible for poor response from the applied inputs, consequently poor nutrient use efficiency and profitability. It is amply visible that micro nutrients are becoming very critical in getting proper response even from macro elements particularly in Indo-Gangatic plain regions. Among the micro-nutrients, the deficiency of Zn is becoming a pan India problem. It has been widely reported that micronutrients enhance nutritional quality, productivity and resiliency to abiotic (drought, high temp) and biotic (pest and diseases) stresses. These positive effects range from 10 to 70%, dependent on the micronutrient, and occur with or without NPK fertilization (Golldack *et al*., 2014). Almost 50% Indian soils are deficit in Zn, and symptoms of Zn deficiency in maize crop are frequently encountered. Skewed use of plant nutrients excluding micronutrients is a major concern for higher fodder maize productivity. Deficit soils produce Zn deficit fodder, which in turn leads to lesser Zn in milk and other animal products. More than one-third of the world's population suffers from Zn deficiency (Stein, 2010), which causes almost 4% of the worldwide burden of morbidity and mortality in under-5-year children and a loss of nearly 16 million global disability-adjusted life years (Black *et al*., 2008). Relationship between zinc deficiencies soil-plants-animal continuum has been reported in several studies. Agronomic fortification through Zn application could be viable option to improve the productivity and quality of fodder crops including maize, which ultimately helps in alleviate zinc deficiency in animals (Kumar *et al.* , 2017; Khinchi *et al.* , 2018; Singh *et al*., 2020). Hence, it is imperative to adopt optimum Zn management practices in crops. Though Zn is required in less quantity but its deficiency leads to poor growth and yield of maize crop. Keeping this in view, an experiment was conducted to find out the productivity and economics of diversified fodder maize based cropping system under different Zn management options/practices.

**Materials and Methods**

***Experimental site*:** The experiment on Zn management in diversified fodder maize based system was conducted with the objective of enhancing cropping system productivity and profitability under irrigated conditions at ICAR-IARI Research Farm (located at latitude: 28°38'23"N, longitude: 77°09'27"E and altitude: 228.6 m MSL) during 2016-17 and 2017-18. The soil of the experiment site was deficit in available Zn and it ranged between 0.3-0.7 ppm. The soil was poor in available N (139.0 kg/ha), medium in available phosphorous (15.2 kg/ha) and high in available potash (300 kg/ha). The pH was slightly saline-sodic (7.8) and the texture was sandy loam.

***Treatment details*:** Experiments were conducted on diversification of maize based cropping system with early mustard and late wheat cultivars in maize (fodder)-mustard-wheat/onion cropping system and response of variable levels of Zn. The design of experiment was strip plot design with three replications. Three factors were considered: cropping systems (maize-wheat, maize-early mustard-late wheat, maize-early mustard-onion) as horizontal strip, whereas Zn levels (0, 2.5 and 5.0 kg/ha) and also Zn solubilizes (ZnS1 and ZnS2) were included as a vertical strip. Pusa Zn soulbilizer (ZnS1 and ZnS2) contained very efficient Zinc-solubilizing bacteria, ZnS1 is a Zn solubilizers of bacterial formulation based on *Bacillus sp*, whereas ZnS2 is consortia based formulation that can solubilize Zinc from various sources like zinc oxide, zinc phosphate and zinc carbonate. These are recommended for different types of soils and can be stored even at elevated temperature. Bacterial protectants added to the formulation improve the shelf life, survival of the culture on seed and also help the culture regain active growth under favourable conditions.

***Crop management*:** The field was prepared and sowing of maize (fodder and grain), early mustard, late wheat was done 1-2 July, 10-12 September and 31 Jan-1$^{st}$ Feb, respectively, while the harvesting of these crops was carried out 30$^{th}$ August (maize fodder), 28-29 Oct (maize grain), 25-26 December (early mustard), April 20$^{th}$ (late wheat). The transplanting of onion was done first week of January and was harvested 12-15 May during both the years. African tall of fodder was grown which was harvested after 60 days of sowing. The recommended fertilizers of NPK (80-40-40 kg/ha) was applied. The seed rate for fodder maize was 50-60 kg/ha. Pre- emergence spray of atrazine @ 0.75 kg a.i. was used for weed management in fodder maize crop. The maize hybrid, PHM-1 with stay green characteristics was grown for grain purpose. African tall, promising maize fodder variety was grown, along with early mustard variety (PM 26 and PM 28) and their inclusion as catch crop between the main crops in the cropping system gave additional benefit in terms of economics and farm produce. The late wheat cultivar HD 3118 with average yield is 4.2 t/ha, was sown after harvest of early maturing mustard. The high yielding onion cultivar of 130 days duration, Pusa Riddhi was transplanted after harvest of mustard in 30th December.

***Observations recorded*:** The observations were recorded on different parameters like growth, yield attributes, economics and nutrient uptakes. The Zn recovery efficiency (RE) and production efficiency were estimated with the help of following formulae (Shivay *et al.,* 2008)-

RE %= [(UZn-Ucp) /Zna] × 100 (1)

Where UZn referred to total Zn uptake (kg /ha) in Zn-applied plots; Ucp referred to total Zn uptake (kg/ha) in control plot (no Zn) and Zna referred to zinc applied (kg/ha)

Production efficiency (kg/ha/day) = Total economical yield/ A/D (2)

Where economical yield referred to grain or fodder biomass, A referred to area in ha and D referred to duration of the crop or cropping system in days.

***Statistical analysis*:** The data on various parameters were statistically analysed using Fisher's analysis of variance technique and the treatments means were compared by Duncan's Multiple Range (DMR) test at level of 0.05 probabilities. The standard analysis of variance (ANOVA) test was performed using SPSS 17.0 statistical software to compare the treatment means for each year separately.

**Results and Discussion**

***Fodder productivity and economics of maize*:** The pooled data revealed that fodder productivity of maize under different Zn management options varied significantly (Table 1) and higher green and dry fodder productivity of maize (African tall) under maize-mustard (Pusa mustard 28)-late wheat (HD 3118) cropping system. Along with fodder productivity, production efficiency and higher net return and B:C ratio were recorded under this cropping system. Green and dry fodder productivity trend was similar, among different cropping systems, fodder maize yield was highest in maize-mustard (PM 28)-onion system and least was in maize-wheat system. In maize–wheat system, the maize was grown with grain variety and the stubbles were harvested for fodder purpose. This was the reason for lower fodder productivity. On dry matter basis, maximum fodder biomass was recorded in maize-mustard (PM 26, 28)-onion system and this was 6 and 10% higher over maize-wheat system. Production efficiency was almost similar in all the cropping systems except in maize-wheat system, where the data on maize crop was only used for comparison. The range of production efficiency on green and dry fodder yield basis was 676-766 and 168.9-192 kg/ha, respectively, with maximum per day productivity was in fodder maize grown in maize-mustard-onion system. Gupta *et al*. (2019) also reported higher fodder yield from African tall maize and further improvement in fodder yield under intercropping systems. The economics from fodder maize was significantly influenced by different cropping system and INR 36.8-43.7 thousand/ha was recorded as net return. The B:C ratio of fodder maize was >1 and ranged between 1.53-1.72 (Table 1).

The Zn levels also influenced the fodder maize productivity. As the soil was poor in available Zn (Zn<0.50 ppm), increasing levels of Zn upto 5 kg Zn/ha was recorded with increased fodder maize productivity (Table1). Better growth, agronomic characters and yield were recorded with higher levels of Zn (5.0 kg/ha) but the response between 2.5 to 5.0 kg of Zn/ha was remained statistically at par. Significantly higher ($P<0.05$) green and dry matter production efficiency (744 and 186 kg/ha/day) were recorded with 5.0 kg Zn/ha, over no Zn application (676 and 168 kg/ha/day). There was increase of almost 15% in net return under 2.5 and 5.0 kg/ha Zn application over no Zn application. Significantly higher B:C ratio was also observed under Zn application (1.74 and 1.72) over no Zn application (1.53). Zn solubilizers helped in mobilizing the soil native Zn, and significantly influenced the dry as well as green maize fodder yield (Table 1) along with enhanced production efficiency (green and dry), net return and also B: C ratio. Zinc solubilizers exerted significant impact on productivity and economics of fodder maize production under variable levels of Zn application (Table 2). In case of no Zn application ZnS2 Zn soulblizer proved superior over ZnS1. Similarly with 2.5 kg Zn application ZnS2 resulted significantly higher fodder productivity over ZnS1. Solubilizer ZnS2 was a consortium based formulation which resulted in higher mobilization of Zn from the soil and made it available to the maize crop. Further with increasing levels of Zn (5.0 kg/ha), again ZnS2 was found to be superior in enhancing maize fodder yield. Increase in fodder yield was higher at 2.5 kg Zn/ha application (11.3% increase) compared to increase at 5.0 kg Zn/ha (6.0 %) with Zn S2 over Zn S1.

However, noteworthy observation was recorded in term of net return, 17.2% higher net return was recorded on 2.5 kg Zn/ha and 8.9% increase in net return was on 5.0 kg Zn/ha with ZnS2 over Zn S1 inoculation. Zinc is a critical micro element for plant growth and development. Zn has vital role in stabilization of RNA, DNA, ribosomes and is involved with the immune system of animals, deficiency of which affects the health and milk production severely. About 50% of Indian soils are deficient in Zn (Singh, 2011; Kumar *et al*., 2017). Hamsa and Puttaiah (2012) also reported that 18 kg/ha zinc resulted significant improvement in growth in fodder cowpea due to the enhanced auxin metabolism and increased photosynthetic rate. The positive and encouraging effects of Zn fertilization on growth and yield of corn were also reported earlier (Mousavi *et al*., 2013; Kumar, 2017).

**Table 1.** Maize fodder productivity and economics under variable Zn levels in maize-mustard-wheat/onion cropping systems (pooled data 2016-17 and 2017-18)

| Treatments | Fodder yield (kg/ha) | | Production efficiency (kg/ha/day) | | NR (000' INR/ha) | B:C ratio |
|---|---|---|---|---|---|---|
| ***Cropping systems*** | **Green** | **Dry** | **Green** | **Dry** | | |
| Maize-wheat | 42.0c | 10.5b | 700c | 175.0c | 39.5b | 1.62ab |
| M-M(PM 26)-W | 44.2bc | 10.8ab | 736bc | 184.0bc | 43.1a | 1.66a |
| M-M(PM 28)-W | 45.0ab | 11.3a | 750ab | 188.0ab | 43.7a | 1.68a |
| M-M(PM 26)-O | 44.5b | 11.1a | 742b | 186.0b | 40.8b | 1.57b |
| M-M(PM 28)-O | 46.0a | 11.5a | 766a | 192.0a | 42.9a | 1.65a |
| ***Zn levels*** | | | | | | |
| Control | 40.5b | 10.5b | 676c | 168.9b | 36.8b | 1.53b |
| Zn 2.5 | 44.4a | 11.1a | 739b | 184.8a | 42.6a | 1.74a |
| Zn 5.0 | 44.6a | 11.4a | 744a | 186.0a | 43.9a | 1.72a |
| ***Zn Solubilizers*** | | | | | | |
| ZnS1 | 42.7b | 10.8b | 712b | 178b | 41.6b | 1.6a |
| ZnS2 | 43.6a | 11.3a | 726a | 181.5a | 42.3a | 1.61a |

Within a column, values represented with different lower-case letters indicated significant differences (P<0.05); NR: Net return; INR: Indian rupees; B:C: Benefit cost ratio; M-M-W: Maize-mustard-wheat; M-M-O: Maize-mustard-onion

**Table 2.** Maize fodder yield and economics under different Zn management options (pooled data 2016-17 and 2017-18)

| Treatment combinations | | Fodder yield (t/ha) | | Production efficiency (kg/ha/day) | | Net return (000'INR/ha) | B:C ratio | Profitability (INR/ha/day) |
|---|---|---|---|---|---|---|---|---|
| **Levels** | **Solubilizers** | **GFY** | **DFY** | **GFY** | **DFY** | | | |
| Control | ZnS1 | 39.2c | 10.2b | 653c | 170d | 34.52c | 1.89b | 575c |
| | ZnS2 | 42.5b | 10.7b | 708b | 178cd | 39.25b | 1.90b | 654b |
| Zn 2.5 | ZnS1 | 42.1b | 10.9a | 702b | 182c | 39.86b | 1.91b | 664b |
| | ZnS2 | 46.1a | 11.7a | 768a | 195bc | 44.85a | 2.13a | 748a |
| Zn 5.0 | ZnS1 | 42.5b | 11.2a | 708b | 187c | 40.10b | 2.07ab | 668b |
| | ZnS2 | 46.6a | 12.6a | 777a | 210a | 45.21a | 2.26a | 754a |

Within a column, values represented with different lower-case letters indicated significant differences (P<0.05); INR: Indian rupees; B:C: Benefit cost ratio; GFY: Green fodder yield; DFY: Dry fodder yield

**Table 3.** System productivity and economics of maize based diversified systems (pooled data 2016-17 and 2017-18)

| Cropping systems | WEY (kg/ha) | Production efficiency (kg/ha/day) | | System NR (000'INR/ha) | System profitability (INR/ha/day) |
|---|---|---|---|---|---|
| | | **SP** | **WEY** | | |
| Maize-wheat | 9179c | 212b | 42.2c | 118.03bc | 536b |
| M-M (PM 26)-W | 11834b | 169b | 50.6b | 137.50b | 474b |
| M-M (PM 28)-W | 12252b | 172b | 51.9b | 145.0b | 500b |
| M-M (PM26)-O | 13141a | 100a | 425a | 212.04.0a | 686a |
| M-M (PM 28)-O | 13240a | 101a | 433a | 213.1a | 696a |

Within a column, values represented with different lower-case letters indicated significant differences (P<0.05); WEY: Wheat equivalent yield; SP: System productivity; NR: Net return; INR: Indian rupees; M-M-W: Maize-mustard-wheat; M-M-O: Maize-mustard-onion

**Table 4.** Nutrient uptake and Zn use efficiency in fodder maize crop (pooled data 2016-17 and 2017-18)

| Treatment combinations | | N (kg/ha) | P (kg/ha) | K (kg/ha) | Zn (g/ha) | ZRE (%) | AZUE (kg DF /kg Zn) |
|---|---|---|---|---|---|---|---|
| Levels | Solubilizers | | | | | | |
| Control | ZnS1 | 83c | 15b | 152c | 130d | - | - |
| | ZnS2 | 83c | 15b | 152c | 217cd | - | - |
| Zn 2.5 | ZnS1 | 81c | 15b | 147c | 242c | 2.74c | 6767c |
| | ZnS2 | 90b | 17a | 164b | 305b | 5.25a | 7383b |
| Zn 5.0 | ZnS1 | 88bc | 16ab | 161b | 265c | 1.83c | 9359a |
| | ZnS2 | 94a | 17a | 171a | 342a | 3.37b | 10053 |

Within a column, values represented with different lower-case letters indicated significant differences ($P<0.05$); ZRE: Zinc recovery efficiency; AZUE: Agronomic zinc use efficiency

***System productivity and economics*:** Maximum system productivity (SP) were recorded from the cropping systems fodder maize- mustard (PM 26)-onion and fodder maize-mustard (PM 28)-onion. It was also evident that higher levels of Zn (2.5 and 5.0 kg/ha) resulted in significantly higher fodder maize productivity over no use of Zn, but 2.5 and 5.0 kg levels of Zn remained at par in its effect. Zinc solubilizer (ZnS1) resulted in higher fodder maize productivity and profitability (Table 2). Maximum system productivity (82.8 t/ha) was recorded in fodder maize-mustard (PM 28)-wheat/onion cropping system. System productivity of maize (fodder)-early mustard (PM 28)-late wheat (HD 3118) was recorded maximum with higher net return and B:C ratio (Table 3). Early mustard varieties (PM 26 and PM 28) resulted in higher seed yield (2.6 t/ha), which increased with ZnS2 solubilizer. This was also reflected in enhanced system productivity based on wheat equivalent yield (WEY; Table 3). Residual Zn effect was observed on subsequent crops in the system, which was also confirmed earlier (Shekhawat *et al*., 2012; Rathore *et al*., 2015). Wheat (HD 3118), late sown cultivar was grown after harvest of mustard in maize-mustard-wheat system. On residual Zn application, with fresh seed treatments with Zn solublizers of wheat seed, higher wheat seed yield was obtained, and a consistent increasing trend in wheat seed yield was observed with increasing levels of Zn application (0 to 5.0 kg Zn/ha). Hence, the ZnS2 was found as better microbial formulation for mobilization of native Zn. Adequate Zn management in onion enhances photosynthates and their translocation in sink (bulb). Prasad (2006) reported enhancement of crop productivity in many crops due Zn application. In terms of abiotic stress mitigation, Zn has been shown to modulate the activity of enzymes, such as the membrane-bound NADPH oxidase involved in the homeostasis of reactive oxygen species, mediate important cellular functions like host defence and signalling during drought or other abiotic stresses (Golldack *et al*., 2014).

***Nutrient usage and Zn use efficiency in fodder maize*:** NPK uptake (kg/ha) was comparatively higher in maize-early mustard (PM 28)-wheat cropping system, and among the different primary elements, uptake of potash was maximum over P and N in fodder maize crop (Table 4). Three levels of Zn (control, 2.5 kg and 5.0 kg/ha) influenced nutrient uptake with two microbial formulations (Zn solubilizer) for maize crop (fodder) in maize (fodder)-early mustard-late wheat-onion cropping system. Maximum Zn uptake in fodder maize was 305 g/ha with applied Zn (5.0 kg/ha). Also with use of microbial formulations like ZnS1 and ZnS2, higher uptake of Zn and NPK was observed. This might be due to higher crop biomass and productivity. Zinc recovery efficiency (ZRE) was highest (5.25%) with 2.5 kg/ha Zn application using ZnS2 solubilizer, whereas with increase in Zn application, zinc recovery efficiency decreased. This was probably due to the fact that the microbes remained more effective under low available Zn conditions. However, the trend in agronomic use efficiency of Zn (AZUE) showed that Zn application @ 5.0 kg/ha along with Zn soubilizer resulted in highest agronomic efficiency (10,053 kg dry maize fodder per kg of Zn applied) and it was higher with 5.0 kg Zn compared to 2.5 kg/ha Zn. It was also observed that ZnS2 resulted higher agronomic efficiency at every level of Zn application (Table 4). Higher the productivity more was the nutrient uptake. However, the use efficiency of applied Zn was found to be low in general. In oilseed crops, the utilization of applied Zn by the crops was found to be <0.5% (Prasad, 2006).

## Conclusion

Based on the findings of the study, it was concluded that fodder maize (African tall) in maize-early mustard-late wheat/onion system resulted higher productivity and net returns with good soil health under application of 2.5 to 5.0 kg Zn/ha. Further, integration of Zn sources with Zn solubilizers resulted in improved uptake of nutrients and higher growth, fodder yield and system productivity along with enhanced system net return and overall profitability. The short duration crops fits well in intensive cropping systems, and could meet multiple requirements of fodder and foods of small and marginal farmers.

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