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Research Articles

Sulphur and Zn management in groundnut *(Arachis hypogaea)*–wheat (*Triticum aestivum*) cropping system: Direct effects on system productivity and residual effects on yield, energetics and Zn biofortification in wheat

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ABSTRACT

A field experiment was conducted over two consecutive rainy (*kharif*) and winter (*rabi*) seasons of 2013–14 and 2014–15 at IARI, New Delhi; to evaluate the direct and residual effects of three sulphur (S) levels (0, 20 and 40 kg S/ha), four zinc (Zn) levels (0, 2.5, 5 and 7.5 kg Zn/ha) and two zinc biofertilizer levels (control and zinc biofertilizer seed treatment) on the performance of groundnut (*Arachis hypogaea* L.)–wheat {*Triticum aestivum* (L.) emend. Fiori & Paol.} cropping system (GWCS). Results pertaining to direct effects on system productivity and residual effects on performance of wheat have been included in this paper. Across the seasons, residual effects of 40 kg S/ha and 5 and 7.5 kg Zn/ha were perceptible on the grain and straw yield, economics, energetics, and S and Zn uptake in wheat crop. Based on 2 years' average, wheat grain yield increased by 4.9%, net profit by ₹ 4 200/ha and energy returns by 8.3×10^3 MJ due to residual effect of 40 kg S/ha over control. On an average, application of 5 and 7.5 kg Zn/ha to groundnut led to increased wheat grain yield by 4.1 and 4.5%, net profit by ₹ 3 300 and ₹ 4 000/ha, and energy returns by 6.1×10^3 and 7.8×10^3 MJ, respectively due to residual fertility. With successive increase in Zn–levels to groundnut, a significant Zn–enrichment of wheat grain and straw was also observed in the current study. However, no residual effect of Zn–solubilizer was noticed on wheat crop. On an average, application of 40 kg S/ha and 5 kg Zn/ha was found to enhance the GWCS system productivity by 16.8 and 12.2% over control, respectively; besides respective significant higher economic–efficiency of ₹ 299 and 287/ha/day. Perceptible variations were also noticed in the system productivity and economic–efficiency following Zn–solubilizer application over the control. Overall, it is concluded that application of S @ 40 kg/ha and Zn @ 5 kg/ha to groundnut had marked residual effect on wheat productivity, profitability, energy dynamics besides Zn biofortification in wheat. The direct application of S @ 40 kg/ha and Zn @ 5 kg/ha also led to significant enhancement in groundnut pod yield, system productivity, system production-efficiency and system economic-efficiency as well, indicating that S @ 40 kg/ha and Zn @ 5 kg/ha are sufficient enough to meet the S and Zn requirement of GWCS.

Key words: Direct effect, Groundnut–wheat cropping system, Residual effect, Sulphur, System productivity, Zinc biofortification

There is dire need to improve the productivity of groundnut-wheat cropping system (GWCS) so as to make it more profitable and enhance its acceptability among Indian farmers. Nutrient management is one of the key agronomic factor affecting crop yields. Continuous and imbalanced use of selected fertilizers (NPK) has resulted in deterioration of soil health, higher cost of production and decline in factor productivity (Pooniya *et al.* 2015). In recent past, sulphur (S) has emerged as 4th major nutrient after N, P and K for increasing the productivity and quality of all the crops, especially oilseeds and pulses as it is involved in the synthesis of essential amino acids and oils in oilseeds being a vital component of co–enzyme involved in oil synthesis (Choudhary 2009). It is also involved in various metabolic and enzymatic processes including photosynthesis, respiration and legume–*Rhizobium* symbiotic N_2 fixation (Choudhary 2009). This role of S is of paramount importance in enhancing the crop productivity especially in legume oilseeds in India, where more than 50% soils are S–deficient (Tewatia *et al.* 2006).

Globally, zinc (Zn) is now recognized as 5th major nutrient deficiency in human beings mainly due to its deficiency in the soil, and thereby in crop produce from such Zn-deficient soils. Zn–deficiency is most widespread on a wide range of soils both under cold and warm climates (Cakmak *et al.* 1996, Suri *et al*. 2011). In Indian soils, Zn–

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deficiency is expected to increase from 42% in 1970 to 63% by 2025 due to continuous depletion of soil fertility (Singh 2011). Zn has specific and essential physiological functions in plant metabolism influencing yield and quality. It is well established fact that crops respond to Zn fertilization and groundnut and wheat are not exception to this. Application of Zn–solubilizers is another viable option to partially meet the plant Zn requirements by enhancing the availability of native soil Zn. In this series, ICAR–Indian Agricultural Research Institute, New Delhi has developed a native Zn–solubilizer (*Bacillus spp*.) which is a new entry in the group of biofertilizers; but still a meager work has been carried–out on its efficacy to substitute Zn requirement of crops under field conditions.

Recent studies conducted on the residual effect of S and Zn has clearly established that both the nutrients have residual effect on succeeding crops (Khan *et al.* 2009, Pooniya *et al*. 2015). A three years 'on–farm' experimentation in Rajasthan (India) have showed that S @ 45 kg/ha to groundnut increased its yield by 661 kg pods/ha (45%), while its residual effects led to yield enhancement in following wheat by 38.6% (Gupta and Jain 2009). Thus, present investigation was undertaken to quantify the direct effects of S and Zn fertilization as well as Zn–solubilizer on groundnut pod yield, system productivity, system production-efficiency and system economic-efficiency *vis-à-vis* residual effects of these treatments on productivity, profitability, energy dynamics and nutrient uptake in succeeding wheat under groundnut–wheat cropping system in semi–arid IGPR.

MATERIALS AND METHODS

A two years field experiment was conducted during rainy (*kharif*) (mid June–mid Nov.) and winter (*rabi*) (mid Nov.–mid April) seasons of 2013–14 and 2014–15 at Research Farm of ICAR–Indian Agricultural Research Institute, New Delhi (28°37´N longitude; 77° 09´E latitude; 228.7 m altitude) to study the direct effect of sulphur (S), zinc (Zn) and Zn–solubilizer levels on rainy season groundnut and their residual effect on succeeding wheat under groundnut–wheat cropping system (GWCS). This paper envisages the direct effects of treatments on system productivity and residual effects on succeeding wheat. The experiment during both years was conducted in affixed lay–out plan in same field. The climate of experimental site is semi–arid with temperature usually warm in most of the period in a year; summer is hot and long and winter is severe and short with average temperatures of 42°C and 15°C, respectively. The mean annual rainfall of New Delhi is 672 mm and more than 80% of which generally occurs during south–west monsoon (July–September) with mean annual evaporation of 850 mm. The soil at site was sandy–loam (Inceptisol; Mahauli series) with bulk density of 1.55 Mg m^3, field capacity 18.1% (w/w), hydraulic conductivity (11.21 mm/hr) and infiltration rate 11.42 mm/hr. It had 0.38% soil organic carbon (SOC), 172 kg $KMnO_4$ oxidizable N/ha, 14.5 kg 0.5 N $NaHCO_3$ extractable P_2O_5/ha, 226 kg 1.0 N NH_4OAc exchangeable K_2O/ha, 11.2 ppm available S, 0.72 ppm DTPA–extractable Zn, 7.8 pH and 0.30 dS/m EC at the start of the experiment during 2013 (Piper 1966, Rana *et al*. 2014).

The treatments comprised of 24 combinations of 3 sulphur (S) levels (0, 20 and 40 kg/ha), 4 Zn levels (0, 2.5, 5, 7.5 kg/ha), and 2 Zn biofertilizer (Native Zn–solubilizer: *Bacillus* spp.) levels (control and Zn–solubilizer). The experiment was conducted in 3 times replicated split–plot design assigning S and Zn levels to main–plots and Zn–solubilizer to sub–plots. Seeds of groundnut GG 20 were dibbled at spacing of 30 × 10 cm. Gap filling was done at 10 days after sowing (DAS) to maintain optimum plant population. Crop received recommended dose of 25 kg N, 60 kg P_2O_5 and 50 kg K_2O/ha through urea, diammonium phosphate and potassium chloride, respectively. After the harvest of groundnut in first week of November, wheat HD 2 967 was sown at spacing of 22.5 cm using 100 kg seed/ha in last week of November to study the residual effect of above treatments applied to groundnut. Wheat received 100% recommended NPK dose (120 kg N, 60 kg P_2O_5 and 50 kg K_2O/ha) through urea, diammonium phosphate and muriate of potash. Full dose of P and K and half N were given as basal and remaining half N was top dressed after first irrigation. Wheat received 6 and 4 irrigations during 2013–14 and 2014–15 to meet the water requirement over and above the rainfall occurred. For weed management, isoproturon @ 0.75 kg a.i./ha + 2,4–D @ 0.5 kg a.i./ha were applied at 25–30 DAS. Crop was harvested in the 3rd week of April during both years.

Net plot of each treatment was harvested at maturity, dried in sun for 4–5 days, weighed for biological yield and threshed for grain and straw yields following standard procedure (Rana *et al*. 2014). Samples from the grains and straw of each plot were also retained for the chemical analysis. Samples of straw and grains of wheat were prepared by observing all precautions (washed initially with tap water followed by dilute hydrochloric acid (0.05 N), deionized water and finally with Zn– free and S–free double distilled water and dried in an air oven at 60± 2ºC) for chemical analysis of S and Zn at harvest. The dried samples of wheat were ground with milling machine and sieved to pass through 40 mesh sieve. The samples were digested using di–acid [perchloric acid ($HClO_4$) + nitric acid (HNO_3) in 3:10 ratio] method. After digestion and extraction of samples, total Zn was estimated with the help of atomic absorption spectrophotometer (perkin Elmer; Model–A. Analyst 100) and total sulphur was estimated with the help of spectrophotometer as described by Prasad *et al.* (2006).

Economic analysis was done following prevailing market prices of the inputs and outputs during respective crop seasons following standard procedures. Energy input and output were calculated using energy equivalents as given by Anonymous (2014). Energy returns were worked–out by subtracting energy input from energy output; and energy use efficiency was worked out by dividing energy output by energy input (Kumar *et al*. 2015a). System productivity in terms of groundnut–pod–equivalent–yield

(GPEY) was calculated as: GPEY = Pod yield of groundnut + [(yield of succeeding wheat crop × price of wheat)/price of groundnut]. Production–efficiency (PE) was expressed as the ratio of system productivity in term of GPEY in kg/ha to total duration of the cropping system in days (Kumar *et al*. 2015b). Like–wise, economic–efficiency was expressed as the ratio of net returns from the cropping system in ₹/ha to total duration of the system in days (Kumar *et al*. 2015b). Critical difference (CD) values at P=0.05 were used to determine the significant of difference between treatment means.

RESULTS AND DISCUSSION

Seasonal variations vis–à–vis wheat productivity

Across the 2 years of experimentation, weather conditions showed wide variation. During 2013, rainy season was wet and rainfall was 102% (1 350 mm) higher than the average rainfall (672 mm). In contrast to this, during *kharif* 2014, the onset of monsoon was late and there were also intermittent drought, and rainfall was just 76% of the average rainfall. These variations in the rainfall resulted in more irrigations to groundnut during 2014 than 2013. Crop yield was also affected due to rainfall and it was less during 2014 than 2013. In winter season, more rainfall was recorded during 2014 (316 mm) than 2013 (220 mm). The effect of abnormal rainfall during winter season of 2014 was observed on wheat crop and productivity of wheat was less during 2014 than 2013 (Table 1). Irrigation water requirement of wheat was less during 2014 than 2013. This adverse effect of high rainfall during winter season may be attributed to favourable conditions for crop lodging, insect–pests, diseases and weed infestation and also less use–efficiency of nutrients especially nitrogen.

Residual effect on wheat crop

Wheat productivity: Of the 2 sulphur levels, residual effect of only 40 kg/ha applied to groundnut was perceptible on the grain and biological yield of wheat as compared to control (S_0) and 20 kg S/ha during both crop seasons (Table 1). Based on 2 years average, wheat grain yield showed improvement of 4.9 and 3.9% due to residual effect of 40 kg S/ha over S_0 and 20 kg S/ha, respectively. Corresponding increase in the biological yield was 4.2 and 3.3%. Wheat harvest index remained unaffected due to residual effect of S across the two crop seasons. Per cent increase in grain yield was more than the biological yield, which established the role of S in dry matter partitioning from source to sink. Results corroborate the findings of Gupta and Jain (2009), and Singh and Saha (1995), where they have reported marked residual effect of applied–S in groundnut-wheat cropping system.

Residual effect of 2.5 kg Zn/ha was not perceptible on wheat grain and biological yield and harvest index (Table 1). But, above parameters exhibited marked improvement when 5 and 7.5 kg Zn/ha was applied to groundnut over control (Zn_0) during both crop seasons; however, the influence of both these Zn levels on yield and harvest index was statistically similar. Based on 2 years average, application of 5 and 7.5 kg Zn/ha to groundnut was found to increase the grain yield of wheat by 4.1 and 4.5%, and biological yield by 3.2 and 3.9% over control (Zn_0) due to residual fertility (Khan *et al.* 2009, Chaudhary *et al.* 2014). Moreover, marked improvement in soil Zn status under 5

Table 1 Residual effect of S, Zn and Zn–solubilizer on grain and biological yield and harvest index of wheat under groundnut–wheat cropping system

Treatment	Grain yield (t/ha)			Biological yield (t/ha)			Harvest index (%)	
	2013–14	2014–15	Average	2013–14	2014–15	Average	2013–14	2014–15
Sulphur levels (kg/ha)								
0	5.42	5.28	5.35	12.15	11.69	11.92	44.4	45.2
20	5.48	5.30	5.40	12.31	11.73	12.02	44.7	45.2
40	5.67	5.54	5.61	12.71	12.13	12.42	44.8	45.6
SEm±	0.21	0.26	0.24	0.03	0.04	0.03	0.14	0.16
CD (P=0.05)	0.63	0.76	0.69	0.09	0.09	0.09	NS	NS
Zinc levels (kg/ha)								
0	5.41	5.25	5.33	12.12	11.68	11.90	44.2	44.9
2.5	5.42	5.27	5.34	12.17	11.70	11.93	44.4	45.1
5.0	5.63	5.48	5.55	12.56	11.98	12.28	44.9	45.7
7.5	5.65	5.49	5.57	12.69	12.05	12.37	44.8	45.6
SEm±	0.25	0.30	0.27	0.04	0.04	0.04	0.16	0.18
CD (P=0.05)	0.72	0.88	0.80	0.11	0.12	0.11	0.47	0.53
Zinc solubilizer								
Control	5.52	5.37	5.45	12.38	11.84	12.11	44.7	45.3
Zn–solubilizer	5.53	5.38	5.45	12.39	11.86	12.13	44.5	45.3
SEm±	0.19	0.16	0.17	0.26	0.28	0.27	0.11	0.12
CD (P=0.05)	NS	NS	–	NS	NS	–	NS	NS

Table 2 Residual effect of S, Zn and Zn–solubilizer on profitability and energy relationships of wheat under groundnut–wheat cropping system

Treatment	Net returns (×10³ ₹/ha)		Net B:C ratio		Energy returns (× 10³ MJ/ha)		Energy-use efficiency	
	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15
Sulphur levels (kg/ha)								
0	54.8	54.4	1.44	1.53	189.7	182.9	12.08	12.49
20	55.9	54.8	1.48	1.54	192.4	183.6	12.13	12.53
40	59.1	58.5	1.56	1.64	199.1	190.2	12.57	12.95
SEm±	0.67	0.63	0.001	0.01	0.45	0.46	0.032	0.037
CD (P=0.05)	1.97	1.85	0.02	0.03	1.34	1.65	0.094	0.110
Zinc levels (kg/ha)								
0	54.6	54.1	1.44	1.52	190.2	182.6	11.99	12.48
2.5	54.8	54.4	1.44	1.53	190.2	182.8	12.05	12.50
5.0	58.3	57.4	1.54	1.61	196.7	187.6	12.43	12.75
7.5	58.8	57.8	1.55	1.62	199.0	188.7	12.56	12.88
SEm±	0.72	0.68	0.01	0.01	0.53	0.55	0.037	0.043
CD (P=0.05)	2.11	2.00	0.03	0.03	1.54	1.62	0.11	0.127
Zinc solubilizer								
Control	56.6	55.8	1.49	1.57	193.7	185.3	12.25	12.64
Zn–solubilizer	56.7	56.0	1.49	1.57	193.8	185.7	12.26	12.66
SEm±	0.28	0.23	0.01	0.01	0.40	0.45	0.025	0.031
CD (P=0.05)	NS	NS	NS	NS				

and 7.5 kg Zn/ha compared to 2.5 kg Zn/ha might have resulted in perceptible residual effect on wheat productivity (Table 1). This may also be attributed to multifarious role of Zn in plant biological processes, and being most important elements in the carbohydrate metabolism (Cakmak *et al.* 1996).

Economics analysis: Data in Table 2 reveals that gain in net returns (NR) in wheat due to residual effect of 40 kg S/ha was ₹4200 and 3500/ha over control (S_0) and 20 kg S/ha, respectively. Benefit: cost ratio (BCR) in wheat also exhibited significant improvement due to marked residual effect of 40 kg S/ha over control (S_0) and 20 kg S/ha (Singh and Saha 1995). Among Zn levels given to groundnut, residual effect of 5 and 7.5 kg Zn/ha remained statistically at par but significantly higher w.r.t. NR and BCR over control (Zn_0) and 2.5 kg Zn/ha during both crop seasons. On an average, 5 and 7.5 kg Zn/ha enhanced the NR by ₹ 3300 and 4000/ha over control (Zn_0). This increase in NR and BCR may be attributed to improvement in wheat yield due to residual effect of Zn (Gupta and Jain 2009). Residual effect of Zn–solubilizer on wheat profitability was non–significant in current study (Table 2).

Energy relationships: During both *rabi* seasons, energy returns (ER) and energy–use–efficiency (EUE) in wheat revealed a statistically detectable variation owing to residual effect of S–levels applied to groundnut (Table 2). Across the S–levels, significant increase in ER and EUE over the control (S_0) was recorded only at higher applied S @ 40 kg/ha to groundnut. Among the Zn–levels applied to groundnut, again a higher residual effect of 5 and 7.5 kg Zn/ha was noticed on ER and EUE of succeeding wheat compared to control (Zn_0) and 2.5 kg Zn/ha. In general, ER and EUE in wheat were significantly higher with 7.5 kg Zn over 5 kg Zn/ha applied to preceding groundnut. This variation in ER and EUE may be attributed to variable grain and stover yield of wheat owing to residual fertility (Table 1). Again, Zn–solubilizer did not show any statistical variation in above energy parameters over control.

Sulphur and zinc uptake: S–uptake in wheat grain, straw and total uptake showed a marked successive influence due to S–levels applied to groundnut with highest S–uptake at 40 kg S/ha (Table 3). The Zn–levels as well as Zn bio–fertilizer applied to groundnut were unable to induce any marked variation in S–uptake in wheat grain, straw and total S–uptake (Table 3). Residual effects of applied–S were significant only on Zn–uptake in wheat grain, where 40 kg S/ha recorded markedly higher Zn–uptake over control (S_0) and 20 kg S/ha. Successive increase in Zn–levels in groundnut resulted in significant increase in Zn–uptake in wheat grain, straw and total uptake due to residual fertility. Again, residual effect of Zn biofertilizer was not perceptible on Zn–uptake in wheat (Table 4). These variations in S– and Zn–uptake in wheat grain and straw may be attributed to variation in wheat grain and straw yield as well as variation in S– and Zn–content in wheat grain and straw owing to residual fertility of S and Zn across the applied–S and Zn-levels (Sharma and Jain 2014).

Direct effect on system productivity, production-efficiency and economic-efficiency

System productivity of groundnut–wheat cropping system in terms of groundnut pod equivalent yield (GPEY)

Table 3 Residual effect of S, Zn and Zn–solubilizer on S uptake in wheat under groundnut–wheat cropping system

Treatment	Sulphur uptake in wheat (kg/ha)				Total sulphur uptake (kg/ha) (Grains + straw)	
	Grains		Straw			
	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15
Sulphur levels (kg/ha)						
0	8.1	7.1	17.3	15.4	25.4	22.5
20	10.1	9.3	22.6	19.6	32.7	28.9
40	12.1	11.2	26.2	23.2	38.3	34.4
SEm±	0.81	0.75	0.96	0.91	0.98	0.92
CD (P=0.05)	2.38	2.20	2.82	2.67	2.88	2.70
Zinc levels (kg/ha)						
0	9.7	8.7	21.7	19.4	31.4	28.1
2.5	9.9	9.2	21.9	19.3	31.8	28.5
5.0	10.7	9.7	22.5	19.7	33.2	29.4
7.5	10.0	9.3	22.0	19.0	32.0	28.3
SEm±	0.96	0.82	1.05	0.98	1.06	1.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Zinc solubilizer						
0	10.1	9.2	22.0	19.4	32.1	28.6
Zn–solubilizer	10.1	9.2	22.1	19.3	32.2	28.5
SEm±	0.69	0.65	0.85	0.76	0.84	0.81
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Table 4 Residual effect of S, Zn and Zn–solubilizer on Zn uptake in wheat under groundnut–wheat cropping system

Treatment	Zinc uptake in wheat (g/ha)				Total zinc uptake (g/ha) (Grains + straw)	
	Grains		Straw			
	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15
Sulphur levels (kg/ha)						
0	156	142	119	107	275	249
20	156	140	121	108	277	248
40	162	147	125	111	287	258
SEm±	1.5	1.2	1.9	1.3	3.4	2.5
CD (P=0.05)	4.6	3.6	NS	NS	NS	NS
Zinc levels (kg/ha)						
0	126	112	88	80	214	192
2.5	147	133	110	98	257	231
5.0	173	158	137	122	310	280
7.5	187	170	151	134	338	304
SEm±	1.8	1.4	2.2	1.9	4.0	3.3
CD (P=0.05)	5.3	4.2	6.5	5.6	11.8	9.8
Zinc solubilizer						
0	158	143	121	108	279	251
Zn–solubilizer	158	144	122	109	280	253
SEm±	1.3	1.0	1.0	1.6	2.3	2.6
CD (P=0.05)	NS	NS	NS	NS	NS	NS

across the direct and residual effects of S and Zn–levels was found to differ significantly during both the crop seasons (Table 5). In the first year, application of 20 kg S/ha enhanced the system productivity by 11.3% over control (S_0). With further increase in S level to 40 kg/ha, the enhancement in system productivity (GPEY) was 4.8% over 20 kg S/ha. Corresponding increase in the second season was 11.3 and 5.3%, respectively. Based on 2 years average, application of 20 and 40 kg S/ha led to 11 and 16.8% increase in system productivity over control (S_0). In contrast to system productivity, production–efficiency (PE) was statistically similar at control (S_0) and 20 kg S/ha. With further increase in S–level to 40 kg S/ha, PE (11.3 and 10.8 kg/ha/day during respective seasons) recorded significant increase over

Table 5 Effect of S, Zn and Zn–solubilizer on groundnut pod yield, system productivity [groundnut–pod–equivalent–yield (GPEY)], production–efficiency and economic–efficiency of groundnut–wheat cropping system

Treatment	Groundnut pod yield (t/ha)		System GPEY (t/ha)		Production efficiency (kg/ha/day)		Economic efficiency (₹/ha/day)	
	2013	2014	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15
Sulphur levels (kg/ha)								
0	1.63	1.53	3.53	3.37	9.7	9.2	240.8	220.8
20	2.00	1.90	3.92	3.75	10.7	10.3	281.1	259.7
40	2.13	2.03	4.11	3.95	11.3	10.8	299.2	277.5
SEm±	0.014	0.015	0.03	0.03	0.04	0.04	2.4	2.5
CD (P=0.05)	0.041	0.043	0.09	0.10	0.12	0.13	7.1	7.3
Zinc levels (kg/ha)								
0	1.69	1.62	3.58	3.46	9.8	9.5	243.0	226.3
2.5	1.98	1.89	3.88	3.71	10.6	10.2	277.0	255.3
5.0	2.07	1.94	4.04	3.86	11.1	10.6	294.8	271.0
7.5	1.94	1.82	3.91	3.75	10.7	10.3	280.0	257.5
SEm±	0.016	0.017	0.04	0.04	0.05	0.05	3.1	2.9
CD (P=0.05)	0.048	0.050	0.11	0.11	0.14	0.15	9.0	8.5
Zinc solubilizer								
0	1.88	1.77	3.81	3649	10.4	10.0	268.8	247.7
Zn–solubilizer	1.96	1.85	3.90	3736	10.7	10.2	278.6	257.5
SEm±	0.011	0.013	0.02	23	0.04	0.04	2.0	2.3
CD (P=0.05)	0.033	0.039	0.06	66	0.12	0.13	5.8	6.7

the control (S_0) owing to direct and residual fertility. Across the S–levels, variation in economic–efficiency (EE) followed the pattern similar to system productivity and the highest EE was recorded as 299.2 and 277.5 ₹/ha/day during respective seasons with 40 kg S/ha. Effect of Zn–levels on system productivity, PE and EE was perceptible only upto 5 kg Zn/ha. Further increase in Zn–level to 7.5 kg/ha induced a slight decrease in system productivity, PE and EE. Decline in productivity at 7.5 kg Zn/ha may be ascribed to its antagonistic interaction with other nutrients in groundnut, thus, resulting in marked decrease in groundnut productivity over 5 kg Zn/ha. On an average, system productivity with 5 kg Zn/ha was found to increase by 7.4 and 12.2% over 2.5 kg Zn/ha and control (Zn_0), respectively; while corresponding increase in PE and EE was 7.7 and 12.2%, and 13.6 and 20%, respectively. Perceptible variations in system productivity and EE were also recorded owing to direct and residual effects of Zn–solubilizer over control (no Zn–solubilizer). The variation in system productivity, PE and EE in GWCS are attributable to direct and residual effects of S and Zn–levels on productivity of respective component crops in GWCS (Gupta and Jain 2009, Sharma and Jain 2014, Manea *et al.* 2015).

From current study, it is concluded that 40 kg S and 5 kg Zn/ha applied to groundnut proved optimum to meet–out the S and Zn requirement of succeeding wheat with marked influence on wheat productivity, profitability, energy dynamics and Zn-uptake as a result of residual fertility. Zn applied to groundnut also led to Zn-biofortification of grains and straw in succeeding wheat. Overall, application of 40 kg S and 5 kg Zn/ha in groundnut are sufficient enough to harness highest system productivity and meet the S and Zn requirement of groundnut–wheat cropping system as a whole in semi–arid IGPR.

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