EVALUATING NITROGEN AND SULFUR FERTILIZATION ON SOYBEAN YIELD FOLLOWING CEREAL RYE

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ABSTRACT

Cover crops such as cereal rye (Secale cereale L.) are widely promoted for their environmental benefits, including nutrient sequestration, reduced nitrate leaching, and soil conservation. However, their influence on subsequent soybean (Glycine max L.) yield and nutrient dynamics remains inconsistent, especially under varying nitrogen (N) and sulfur (S) fertilization regimes. Field trials were conducted during 2024 and 2025 across three sites in Central Illinois—Monmouth, Perry, and Urbana—to evaluate the effect of cereal rye and fertilization on soybean growth, tissue nutrient concentration, and yield. Treatments were arranged in a randomized complete block design with a factorial combination of two cover crop treatments: no cover (NC) and cereal rye (CR), and four fertilizer treatments: untreated control (UTC), N, S, and N+S. Cereal rye biomass and nutrient content varied across locations and years. Soybean biomass was lower following cereal rye at all three locations. Fertilization treatments containing N increased early- and mid-season N tissue concentrations, and those with S increased early- and mid-season S tissue concentrations. Reduced soybean yield following cereal rye was observed only at Urbana. Soybean yield responses to fertilizers alone depended on the location. Monmouth showed higher yields with N+S, Perry had higher yields with UTC, and Urbana showed no significant effect. Soybean yield responded positively to CR-N+S, reaching the highest levels, while in Perry and Urbana, the interaction effect was not significant. Overall, the effects of cereal rye and different fertilizer regimes on soybean yield varied across locations; however, soybean yield following CR combined with N+S was consistently similar or higher than that of NC-UTC, suggesting that using CR as a cover crop can enhance soybean production sustainability.

INTRODUCTION

The United States ranks as the second-largest soybean (Glycine max L.) producer in the world, with 113 metric tons, representing 29% of the total global production (USDA-FAS, 2024)The Midwest produces more than 80% of the soybeans in the United States, with Illinois as the leading producer with 16% of the total USA production(USDA-NASS, 2024). Illinois's predominant cropping system is a biennial corn [Zea mays (L.) Merr.] and soybean rotation. This system demands high fertilizer inputs, primarily nitrogen, which during fallow winter and spring months leads to significant N03-N leaching (Owens et al., 1995; Ruffo et al., 2004).

Among the environmental benefits of cover crops, especially cereal rye (Secale cereale L.), are nitrogen sequestration, reduction in N03 leaching, improved soil nutrient cycling, enhanced water infiltration, and soil erosion control, all of which support longterm agricultural sustainability (Ruffo et al., 2004; Wagena & Easton, 2018). Although these environmental benefits are well documented, the agronomic benefits for soybean production remain debated. Multiple studies across the Midwest region of the US have shown that cereal rye can increase (Moore et al., 2014), decrease (Eckert, 1998), or have no effect on soybean yield (De Bruin et al., 2005). These mixed results have created uncertainty among farmers and have limited the adoption of this cover crop. Furthermore, they highlight the need for more detailed research to better understand the system and develop adaptive management strategies to achieve more consistent soybean yield optimization.

Soybean yield reductions following cereal rye termination have been attributed to planter interference and incomplete termination, which can lead to stand reductions(Schipanski et al., 2014). However, the possibility that cereal rye's nutrient uptake may result in lower nitrogen (N) and sulfur (S) levels, both critical for soybean development and nodulation, has been overlooked. Many studies have investigated the impact of nitrogen fertilization at different stages of soybean growth, generally finding little to no yield increase, with results heavily influenced by environmental factors such as weather and soil types (Mourtzinis et al., 2018; Vonk et al., 2024) Similarly, research on sulfur has shown that increasing S fertilization does not consistently boost soybean yield (Fleuridor et al., 2023; Letham et al., 2021).

The limited existing literature indicates that the effects of nitrogen or sulfur on soybean yield are inconclusive and highly location-dependent. Moreover, these studies often did not consider cereal rye as a cover crop, focusing instead on the effects of either nitrogen or sulfur alone. Therefore, this research aims to: 1) evaluate the impact of cereal rye on soybean yield in Central Illinois, and 2) examine how nitrogen, sulfur, and their combination influence soybean yield following cereal rye cover crop.

MATERIALS AND METHODS

Experimental Design, Cereal Rye Cover Crop and Soybean Management.

The experiment was conducted in 2024 and 2025 across 3 site-years in Central Illinois. Field trials were established in small plots at Northwestern Illinois Agricultural Research and Demonstration Center near to Monmouth, Warren Co., in JWCC Agricultural Education Center near to Perry, Pike Co., and UIUC Crop Science & Education Center near to Urbana, Champaign Co., Predominant soils in Monmouth, Perry and Urbana were muscatune silt loam, Bluford silt loam and Flanagan silt loam, respectively, classified as moderate to poorly drained.

The experiment was arranged using randomized complete block design with 4 replications per site. Each replication had eight treatments in a 2-way factorial combination, where cover crop factor had two levels: cereal rye [CR] and no cereal rye (NC), and the fertilizer factor with four levels: unfertilized check [UTC], Nitrogen [N] (40 lbs. N ac^{-1} as Urea), Sulfur [S] (20 lbs. S ac^{-1} as pelletized Gypsum), and the combination of N and S in their respective rates [N+S]. Fertilizers were broadcasted at planting. The cereal rye cover crop was no-till drilled after corn harvest during mid to late October, with a target seeding rate of 50 lbs. ac^{-1} on 7.5-inch rows. The cereal rye termination was targeted at 12-16 inches tall or two weeks before soybean planting by spraying glyphosate (N-phosphonomethyl glycine) at 1 qt ac^{-1} rate. Soybean was no-till planted with 30-inch row spacing at 150.000 seeds ac^{-1}. For both growing seasons, Monmouth was planted in mid-May, Perry in late April, and Urbana in late May. Two rows per plot were harvested using an experimental combine. All yields were adjusted to 13% moisture.

In Season Sampling

Before termination, cereal rye aboveground biomass was sampled from a 5.4 ft^2 quadrats at four random locations in each plot. Samples were oven-dried at 140ºF , ground to pass a 1-mm screen using a Wiley mill and analyzed for nutrient concentrations by a commercial laboratory (A&L Great Lakes, Fort Wayne, Indiana). At the same moment, composite soil samples (between 8 and 12 cores at two depth) were collected from each block for the cereal rye and no cereal rye plots. For soybean, at V4 growth stage aboveground biomass was collected

During soybean growing season, Whole-plant biomass samples were collected at V4 growth stage from two 1-meter subsamples to make a composite sample per plot. Stand counts were taken at the same moment by counting 4 linear meters per plot. A composite sample of 30 most recently mature trifoliate leaves were taken at R2 growth stage. Samples were processed and analyzed for nutrient concentrations following the same procedures as cereal rye biomass.

Statistical Analysis

Data was analyzed using R software version 4.5.1. A linear mixed effects model was performed to analyze the response variables across years. Cover crop and fertilizer treatment was set as fixed effects, and year and block was included as random effects. Mean differences were calculated using Tukey's HDS test at a significant level of alpha 0.10.

RESULTS AND DISCUSSION

Cover Crop growth, N and S analysis, and baseline soil testing.

Cereal rye spring biomass and nutrient concentrations varied considerably across locations and years (Table 1). These differences across locations can be explained by the varying termination timings, with Monmouth being terminated in late April, Perry in mid-April, and Urbana in early May, in both years. The C:N ratio ranged from 14 to 30 across sites and years, with lower values in 2025 at Monmouth due to higher N concentrations, indicating potentially faster residue mineralization. In contrast, the higher ratio at Urbana in 2025 suggests early-season N immobilization and slower decomposition potential.

Table 1. Average cereal rye aboveground biomass, nitrogen (N) and sulfur (S) concentration, total N and S content, and C:N ratios for 2024 and 2025 growing seasons.

Year	Biomass	N conc	S conc.	N cont.	S cont.	C:N
	lb ac^{-1}	----------%------------		---------- lb ac^{-1}-----		ratio
			Monmouth			
2024	489	1.93	0.15	9	0.75	22
2025	827	3.14	0.23	26	1.93	14
			Perry			
2024	1158	1.64	0.14	19	1.66	26
2025	1429	1.71	0.15	25	2.10	25
			Urbana			
2024	2127	1.65	0.13	35	2.75	26
2025	1351	1.44	0.14	20	1.87	30

Table 2. Spring soil test levels at 0-6 inches depth sampling in each site. (NC = no cover; CR = cereal rye).

Year	Treatment	Depth	OM	pH	Bray-1 P	S	K
		(in)	%		lb ac^{-1}	lb ac^{-1}	lb ac^{-1}
			Monmouth				
2024	CR	6	4.22	7.2	54.5	33.6	294.5
	NC	6	4.08	7.1	50.5	41.4	300.5
2025	CR	6	3.72	6.9	53	44.8	210
	NC	6	3.8	7	58	44.8	238
			Perry				
2024	CR	6	2.2	5.6	25	34.7	209.5
	NC	6	2.22	5.3	26	41.4	223
2025	CR	6	2.6	6	20	34.7	233.5
	NC	6	2.45	6	23.5	29.1	232
			Urbana				
2024	CR	6	3.4	6.8	59	45.9	235
	NC	6	3.33	6.7	59.5	45.9	249
2025	CR	6	4.22	6.6	52.5	48.2	306
	NC	6	4.08	6.4	36	50.4	289.5

Soybean Growing Season Response to CC and Fertilizers Treatments.

Monmouth

Soybean aboveground biomass measured at the V4 growth stage showed a significant effect for the main factors, cover crop and fertilizer, but not for their interaction. Averaging across years, soybean biomass was significantly lower in plots following cereal rye (NC = 442 vs CR = 405 lb ac^{-1}, Table 3). The application of N and N+S resulted in significantly higher biomass compared to the untreated control. N concentration at early-season did not differ between treatments, nor the interaction. In contrast, sulfur fertilization was reflected in S tissue concentration early in the season, showing a significant interaction. Treatments that included sulfur in both NC (0.29%) and CR (0.31%) showed the highest S concentration compared to UTC (0.24%) and N alone (NC = 0.23%, CR = 0.20%). The N:S ratio was significant for the interaction; treatments under CC and NC with N fertilization had the highest N:S ratio due to lower sulfur concentrations.

Mid-season N concentrations showed significant differences for the main effects and their interaction. CR without fertilizer treatment had the lowest N concentration (5.42 %) compared to other treatment interactions, which ranged from 5.69% to 5.57 %. Additionally, S concentration and N:S ratio were significantly affected by the fertilizer's main effect. The S concentration in S (0.34%) and N+S (0.35%) treatments was significantly higher compared to N (0.32%) alone or UTC (0.32%), resulting in a higher N:S ratio in treatments with low S levels such as N (17.2) and UTC (16.9). This indicates that early-season trends continued through mid-season.

After two growing seasons, soybean yield was significantly affected by fertilizer and its interaction with the cover crop (Table 6). The application of N+S (73.8 bu ac-1) and N (71.8 bu ac-1) resulted in significantly higher yields compared to the UTC (67 bu ac-1). S application (70.7 bu ac-1) was not statistically different from any other treatment. Regarding the interaction, soybean yield ranged from 75 to 70.6 bu ac-1, with CR-N+S showing the highest yield response and NC-N the lowest; however, they were not statistically different, except for CR-UTC, which yielded 62.7 bu ac-1.

Table 3. Effects of cover crop, fertilizer, and their interactions on soybean nutrient concentrations, aboveground biomass, and plant population at early (V4 growth stage) and mid-season (R2) at Monmouth.

	V4 Growth Stage					R2 Growth Stage		
	N conc.	S conc.	N:S	DM Biomass	Plant Population	N conc.	S conc.	N:S
	%			lb ac^{-1}	pl ac^{-1}	%		
Cover Crop								
NC	4.10	0.26	16.0	442 a†	133393	5.68 a	0.34 a	16.6
CR	4.08	0.26	16.1	405 b	132272	5.57 b	0.33 b	16.7
Fertilizer								
N+S	4.16	0.27 b	18.4 a	446 a	128455	4.96 a	0.35 a	16.1 c
N	4.04	0.22 d	16.8 b	467 a	133600	4.75 ab	0.32 b	17.2 a
S	4.08	0.30 a	15.2 c	408 ab	133517	4.82 a	0.34 a	16.4 bc
UTC	4.08	0.24 c	13.6 d	374 b	135758	4.50 b	0.32 b	16.9 ab
CC:Fertilizer								
NC-N+S	4.17	0.26 b	15.3 cd	451	127957 a	5.69 a	0.35	16.2
NC-N	4.06	0.23 c	17.4 b	480	130446 a	5.69 a	0.34	16.9
NC-S	4.08	0.29 ab	14.2 de	448	137417 a	5.67 a	0.35	16.5
NC-UTC	4.11	0.24 c	16.9 b	391	133268 a	5.67 a	0.33	17.0
CR-N+S	4.15	0.27 b	15.1 d	441	128953 a	5.66 a	0.35	16.2
CR-N	4.03	0.20 d	19.4 a	455	136753 a	5.57 ab	0.32	17.5
CR-S	4.08	0.31 a	13.1 e	368	129616 a	5.64 a	0.35	16.4
CR-UTC	4.04	0.24 c	16.7 bc	357	138247 a	5.42 b	0.32	16.9
p-values								
CC	0.432	1.000	0.633	0.077	0.604	0.003	0.050	0.615

Fertilizer	0.138	<0.001	<0.001	0.012	0.114	0.045	< 0.001	< 0.001
CC:Fertilizer	0.889	0.002	0.002	0.657	0.100	0.090	0.300	0.536

†Treatments means within a column followed by different letters are significantly different at p < 0.1 by the Tukey's HSD test.

Perry

Soybean aboveground biomass measured at the V4 growth stage showed a significant effect only for the main factor, cover crop. Averaged across years, soybean biomass was significantly lower in plots following cereal rye (NC = 362 vs CR = 290 lb ac-1, Table 4). Additionally, plant population was significantly reduced in plots with cereal rye.

N concentration early in the season showed significant effects from cover crop and fertilizer main effects, but not from their interaction. Cereal rye reduced N concentration to 3.43% compared to plots under NC (3.55%). The application of fertilizer containing N significantly increases N tissue concentration (N+S = 3.52%, and N = 3.72%). Similarly, fertilizers containing S (S = 0.28% and N+S = 0.26%) showed higher S tissue concentrations. Likewise, the N:S ratio varies significantly among fertilizer treatments, ranging from 17.3 (N) to 11.9 (S). N application resulted in a higher N:S ratio due to the reduction in S concentration.

Mid-season N concentrations varied significantly among the main effects. Plots with cereal rye had a lower value (4.65%) compared to NC (4.90%). For the fertilizer main effect, S fertilizer resulted in a lower N tissue concentration (4.66%). Regarding S tissue concentration, plots without fertilization had the lowest concentration (0.28%).

After two growing seasons, soybean yield ranged from 71 to 62 bu ac-1 and was significantly affected by the main effect of fertilizer (Table 6). UTC showed the highest yield; however, it was not statistically different from the N+S and N fertilizer treatments, except for sulfur.

Table 4. Effects of cover crop, fertilizer and their interactions on soybean nutrient concentrations, aboveground biomass and plant population at early (V4 growth stage) and mid-season (R2) at Perry.

	V4 Growth Stage					R2 Growth Stage		
	N conc.	S conc.	N:S	DM biomass	Plant Population	N conc.	S conc.	N:S
	%			lb ac-1	pl ac-1	%		
Cover Crop								
NC	3.55 a†	0.25	14.5	362 a	128871 a	4.90 a	0.31	16.0 a
CR	3.43 b	0.25	14.0	290 b	114556 b	4.65 b	0.30	15.5 b
Fertilizer								
N+S	3.52 ab	0.27 a	13.1 bc	359	123891	4.91 a	0.32 a	15.1 b
N	3.72 a	0.21b	17.3 a	336	121734	4.82 ab	0.29 bc	16.5 a
S	3.35 b	0.28 a	11.9 c	310	120738	4.66 b	0.30 ab	15.0 b
UTC	3.38 b	0.23 b	14.6 b	300	120489	4.73 ab	0.28 c	16.4 a
Interaction								
NC-N+S	3.62	0.26	13.9	394	131940	5.02	0.32	15.5
NC-N	3.84	0.22	17.7	388	129451	4.94	0.29	17.0
NC-S	3.33	0.29	11.9	332	126630	4.78	0.31	15.3
NC-UTC	3.43	0.24	14.5	336	127459	4.89	0.30	16.6
CR-N+S	3.42	0.27	12.5	324	115842	4.81	0.32	14.9
CR-N	3.60	0.21	17.0	284	114016	4.70	0.29	16.2
CR-S	3.37	0.29	12.0	268	114846	4.54	0.31	14.9

CR-UTC	3.34	0.23	14.7	284	113518	4.58	0.28	16.4
p-values								
CC	0.042	0.958	0.340	0.001	< 0.001	< 0.001	0.251	0.060
Fertilizer	< 0.001	< 0.001	< 0.001	0.206	0.934	0.069	< 0.001	< 0.001
CC:Fertilizer	0.364	0.735	0.599	0.842	0.983	0.973	0.735	0.866

†Treatments means within a column followed by different letters are significantly different at p < 0.1 by the Tukey's HSD test.

Urbana

As with other locations, soybean aboveground biomass was significantly lower in plots following cereal rye (113 lb ac-1) than in the no cover crop (171 lb ac-1, Table 5). Additionally, this site showed a significant interaction, where NC+S (425 lb ac-1) had the highest biomass compared to CR+S (253 lb ac-1). Mid-season, the sulfur concentration and N:S responses persisted throughout the season with the same significant levels observed at V4. After two growing seasons, soybean yield was only significantly affected by the cover crop, with cereal rye producing 61.4 bu ac-1 compared to NC with 63.9 bu ac-1 (Table 6).

Table 5. Effects of cover crop, fertilizer and their interactions on soybean nutrient concentrations, aboveground biomass in early (V4 growth stage) and mid-season (R2) at Urbana.

	V4 Growth Stage				R2 Growth Stage		
	N conc.	S conc.	N:S	DM biomass	N conc.	S conc.	N:S
	%			lb/ac	%		
Cover Crop							
NC	4.09	0.29 b†	13.7 a	171 a	4.94	0.32	15.6
CR	4.02	0.30 a	13.1 b	133 b	4.87	0.32	15.4
Fertilizer							
N+S	4.09	0.3143 a	13.0 b	366 a	4.89	0.32 ab	15.2 b
N	4.05	0.2846 b	14.2 a	339 ab	4.99	0.30 b	16.4 a
S	4.01	0.3246 a	12.4 b	329 ab	4.83	0.32 a	14.8 b
UTC	4.05	0.2912 b	14.0 a	312 b	4.89	0.31 ab	15.4 b
Interaction							
NC-N+S	4.07	0.31	13.3	397 ab	4.87	0.32	15.1
NC-N	4.09	0.28	14.4	343 abc	5.07	0.31	16.6
NC-S	4.08	0.31	13.0	425 a	4.83	0.32	15.0
NC-UTC	4.11	0.29	14.4	350 abc	4.98	0.32	15.6
CR-N+S	4.10	0.32	12.9	335 bc	4.91	0.32	15.3
CR-N	4.01	0.28	14.1	315 cd	4.91	0.30	16.3
CR-S	3.95	0.33	12.0	253 d	4.84	0.33	14.7
CR-UTC	4.00	0.29	13.6	274 cd	4.80	0.32	15.4
p-values							
CC	0.108	0.098	0.012	< 0.001	0.237	0.920	0.562
Fertilizer	0.723	< 0.001	< 0.001	0.067	0.291	0.065	< 0.001
CC:Fertilizer	0.645	0.610	0.738	0.006	0.404	0.874	0.927

†Treatments means within a column followed by different letters are significantly different at p < 0.1 by the Tukey's HSD test.

Table 6. Effect of cover crop and fertilizer treatment and their interaction on soybean yield across year by location in central Illinois.

	Soybean Yield (bu ac^{-1})		
	Monmouth	Perry	Urbana
Cover Crop			
NC	71.8	68.4	63.9 a[†]
CR	69.8	67.3	61.4 b
Fertilizer			
N+S	73.8 a	68.8 ab	62.1
N	71.8 a	67.6 ab	63.3
S	70.7 ab	64.5 b	61.2
UTC	67.0 b	70.6 a	64.0
CC:Fertilizer			
NC-N+S	72.5 a	69.8	61.6
NC-N	70.6 a	71.0	62.7
NC-S	72.8 a	62.0	60.0
NC-UTC	71.3 a	70.9	61.4
CR-N+S	75.0 a	67.8	62.5
CR-N	70.9 a	64.1	63.9
CR-S	70.7 a	66.9	62.4
CR-UTC	62.7 b	70.4	66.6
p-values			
CC	0.132	0.500	0.085
Fertilizer	0.005	0.073	0.492
CC:Fertilizer	0.025	0.103	0.687

[†]Treatments means within a column followed by different letters are significantly different at $p < 0.1$ by the Tukey's HSD test.

REFERENCES

De Bruin, J. L., Porter, P. M., & Jordan, N. R. (2005). Use of a Rye Cover Crop following Corn in Rotation with Soybean in the Upper Midwest. Agronomy Journal, 97(2), 587–598. https://doi.org/10.2134/agronj2005.0587

Fleuridor, L., Fulford, A., Lindsey, L. E., Lentz, E., Watters, H., Dorrance, A., Minyo, R., Richer, E., Chaganti, V., Subburayalu, S., & Culman, S. W. (2023). Ohio grain crop response to sulfur fertilization. Agronomy Journal, 115(4), 2007–2016. https://doi.org/10.1002/agj2.21328

Letham, J. L., Ketterings, Q. M., Cherney, J. H., & Overton, T. R. (2021). Impact of sulfur application on soybean yield and quality in New York. Agronomy Journal, 113(3), 2858–2871. https://doi.org/10.1002/agj2.20690

Moore, E. b., Wiedenhoeft, M. h., Kaspar, T. c., & Cambardella, C. a. (2014). Rye Cover Crop Effects on Soil Quality in No-Till Corn Silage–Soybean Cropping Systems. Soil Science Society of America Journal, 78(3), 968–976. https://doi.org/10.2136/sssaj2013.09.0401

Mourtzinis, S., Kaur, G., Orlowski, J. M., Shapiro, C. A., Lee, C. D., Wortmann, C., Holshouser, D., Nafziger, E. D., Kandel, H., Niekamp, J., Ross, W. J., Lofton, J., Vonk, J., Roozeboom, K. L., Thelen, K. D., Lindsey, L. E., Staton, M., Naeve, S. L., Casteel, S. N., … Conley, S. P. (2018). Soybean response to nitrogen application across the United States: A synthesis-analysis. Field Crops Research, 215, 74–82. https://doi.org/10.1016/j.fcr.2017.09.035

Owens, L. B., Edwards, W. M., & Shipitalo, M. J. (1995). Nitrate Leaching through Lysimeters in a Corn-Soybean Rotation. Soil Science Society of America Journal, 59(3), 902–907. https://doi.org/10.2136/sssaj1995.03615995005900030039x

Ruffo, M. L., Bullock, D. G., & Bollero, G. A. (2004). Soybean Yield as Affected by Biomass and Nitrogen Uptake of Cereal Rye in Winter Cover Crop Rotations. Agronomy Journal, 96(3), 1. https://doi.org/10.2134/agronj2004.0800

Schipanski, M. E., Barbercheck, M., Douglas, M. R., Finney, D. M., Haider, K., Kaye, J. P., Kemanian, A. R., Mortensen, D. A., Ryan, M. R., Tooker, J., & White, C. (2014). A framework for evaluating ecosystem services provided by cover crops in agroecosystems. Agricultural Systems, 125, 12–22. https://doi.org/10.1016/j.agsy.2013.11.004

USDA-FAS. (2024). Production | USDA Foreign Agricultural Service. https://www.fas.usda.gov/data/production?commodity=almonds&commodity=soybean-oil&commodity=soybeans&commodity=soybean-meal&commodity=rice

USDA-NASS. (2024). USDA - National Agricultural Statistics Service—Statistics by Subject Results. https://www.nass.usda.gov/Statistics_by_Subject/result.php?E4184AC1-EE35-347A-94F2-F087DEE64F55&sector=CROPS&group=FIELD%20CROPS&comm=SOYBEANS

Vonk, J., Nafziger, E., & Preza Fontes, G. (2024). Soybean response to nitrogen fertilizer in different soils. Crop, Forage & Turfgrass Management, 10(2), e20304. https://doi.org/10.1002/cft2.20304

Wagena, M. B., & Easton, Z. M. (2018). Agricultural conservation practices can help mitigate the impact of climate change. Science of The Total Environment, 635, 132–143. https://doi.org/10.1016/j.scitotenv.2018.04.110