2021 Final Report
Summary Sheet

Grantee Information

Project Title:	Water Quality and Agronomic Impacts of Gypsum Applications in Southern Illinois
Institution:	Southern Illinois University Carbondale
Primary Investigator:	Karl W.J. Williard, Jon E. Schoonover, and Gurbir Singh
NREC Project #	NREC-2018-1-26939-300

Is your project on target from an IMPLEMENTATION standpoint? ☒ **Yes** ☐ **No**
If you answered "no" please explain:

Is your project on target from a BUDGET standpoint? ☒ **Yes** ☐ **No**
If you answered "no" please explain:

Based on what you know today, will you meet the objectives of your project on-time and on-budget? ☒ **Yes** ☐ **No**
If you answered "no" please explain:

Have you encountered any issues related to this project? ☐ **Yes** ☒ **No**
If you answered "yes" please explain:

Have you reached any conclusions related to this project that you would like to highlight? ☒ **Yes** ☐ **No**
If you answered "yes" please explain:
They are summarized below in on the first page.

Have you completed any outreach activities related this project? Or do you have any activities planned? ☒ **Yes** ☐ **No**
If you answered "yes" please explain and provide details for any upcoming outreach:

- The project was presented at a virtual poster session hosted by SIU on April 15, 2021.

- The project was highlighted virtually through video presentation and poster at conference conducted by Universities Council on Water Resources (UCOWR) Conference which was held in

June 2021. In addition to the formal presentation, graduate students had the opportunity to discuss the project with several professionals and industry experts at the conference.

- Most importantly, this project was highlighted through oral and poster presentation SIU Ag Field Day, conducted at SIU Farms on July 9, 2021. Farmers, related stakeholders and professionals from the agriculture and natural science industry took part in the program.

SUMMARY

In assessing impacts of FGD gypsum application on reducing P losses in surface runoff, we observed that the lowest amount of dissolved reactive phosphorus and total phosphorus losses in 2021 was from the gypsum treatment of 1 ton per ace while the highest was in the control treatment. Our data show Total Suspended Solids (TSS) loads were lowest at 2 tons per acre while the control had the highest loads. Calcium Sulfate dissociation in gypsum allowed the calcium to bind to soluble phosphorus, which transformed readily soluble phosphorus to less soluble calcium phosphate which remained in soil for a longer time.

In a comparison between pre-treatment (2020) and post treatment (2021) surface runoff samples, it was found that losses of DRP loads in 2021 was reduced by 50%, 20% and 33% in 1 ton per acre treatment, 2 tons per acre treatment and 6 tons per acre treatment, respectively. Similarly, Total phosphorus loads decreased in 2021 by 40%, 0% and 12.5 % in 1 ton per acre treatment, 2 tons per acre treatment and 6 tons per acre treatment, respectively. Comparison showed that TSS load values decreased in 2021 by 83%, 85% and 78% in 1 ton per acre, 2 tons per acre and 6 tons per acre, respectively.

In terms of grain yield, soybean yield data from Fall 2020 showed that Gypsum plots had the highest yield (72.9 bushels per acre) followed by control (70.9 bushels per acre), Sulfur (69.3 bushels per acre) and Lime (68.6) treated plots. Economic analysis shows application of 1 ton of gypsum per acre on an alternate year basis to a standard corn-soybean rotation in southern Illinois can reduce phosphorus loads by 2.19 to 3.29 pounds per acre per year compared to control. The cost per pound of phosphorus removed averaged $2.98 per pound across the study.

Table 1. Comparison between Pre and Post Gypsum Treatment loads and Control Treatment loads for DRP, TP, and TSS in surface runoff.

Parameter	Treatments	Pre-Treatment Loads kg/ha (2020)	Post Treatment Loads kg/ha (2021)	Change (%)
Dissolved Reactive Phosphorus (DRP)	1 ton/acre	0.14	0.07	50
	2 tons/acre	0.15	0.12	20
	6 tons/acre	0.12	0.08	33.33
	control	0.16	0.11	31.25
Total Phosphorus (TP)	1 ton/acre	0.20	0.12	40
	2 tons/acre	0.17	0.17	0
	6 tons/acre	0.16	0.14	12.5
	control	0.18	0.22	-22.22*
Total Suspended Solids (TSS)	1 ton/acre	141.30	22.83	83.84
	2 tons/acre	144.30	20.93	85.49
	6 tons/acre	173.40	37.43	78.41
	control	168.70	50.72	69.93

Negative values denote increases in export in post-treatment period compared to pre-treatment period, while positive values denote decreases in export in the post-treatment period compared to pre-treatment period.

Water Quality and Agronomic Impacts of Gypsum Applications in Southern Illinois

Gypsum (Calcium sulfate dihydrate) application has been proposed as a practice to reduce phosphate leaching, as the calcium binds with available phosphate in the soil. This research will determine the impact of gypsum applications on water quality and yield on Illinois soils and provide the Illinois agricultural community an independent assessment of gypsum's ability to serve as a phosphate abatement tool.

The two main objectives of this research were to evaluate different application rates of flue gas desulfurization (FGD) gypsum for reducing P losses in surface runoff; and to determine the impact of FGD gypsum application on crop production and soil physical properties. To test these two objectives, a surface runoff study and a yield plot study were established on fields with high soil phosphorus levels. In the surface runoff study, four treatments including: control, gypsum @ 1 ton/acre, gypsum @ 2 tons/acre and gypsum @ 6 tons/acre were applied to assess the effect of gypsum applications on runoff water quality. For the yield study, four treatments including a control, gypsum @ 1 ton/acre, calcium (Ca) as lime at the same rate of Ca as supplied by gypsum, and sulfur as elemental sulfur at the same rate of S as supplied by gypsum, were applied to determine which element in gypsum may be impacting yield and soil properties.

Additional objectives were to conduct economic analysis (cost benefit ratio assessment) on the application of FGD Gypsum for farm level yield sites and to assess the probability of heavy metal toxicity post FGD Gypsum application in soil and surface runoff water.

1. Objective 1: To evaluate different application rates of flue gas desulfurization (FGD) gypsum for reducing P losses in surface runoff

In the surface runoff study, we collected 65 samples from rain events since 2018, with 19 samples in 2021. From these events, 59 have been tested in laboratory for Dissolved Reactive Phosphorus (DRP), Total Phosphorus (TP), Total Suspended Sediment (TSS) and Sulfur (S) loads. Six events were discarded because they did not meet the sampling standards. Sample collection will be completed by December 2021. This report includes presentation of statistical analysis of data values from 19 recent rain events from 1/1/2021 to 9/22/2021.

1.1. Results

1.1.1. Dissolved Reactive Phosphorus (DRP) results from 1/1/2021 – 9/22/2021

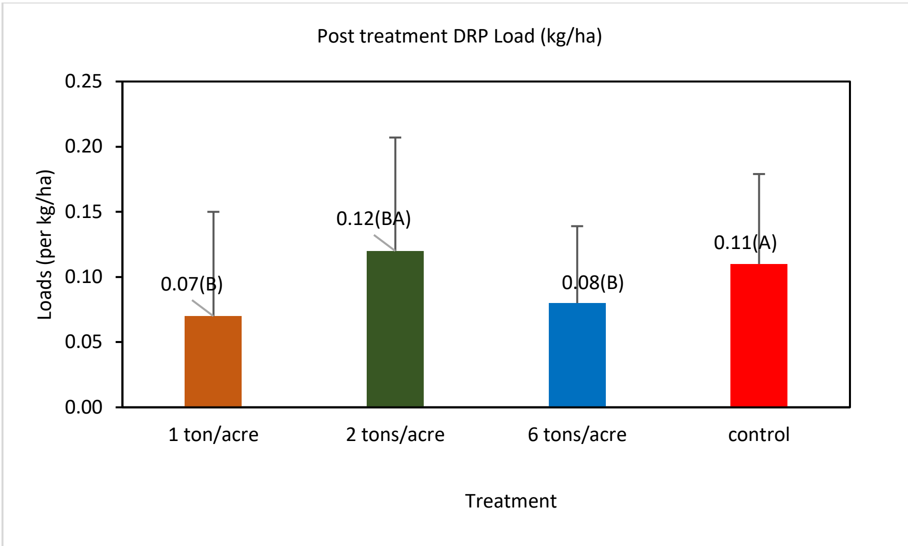

Figure 1 Dissolved Reactive Phosphorus (DRP) load in surface runoff from gypsum treatments and control during post treatment. Means with different letters are significantly different at alpha=0.05

1.1.2. Total Phosphorus (TP) results from 1/1/2021 – 9/22/2021

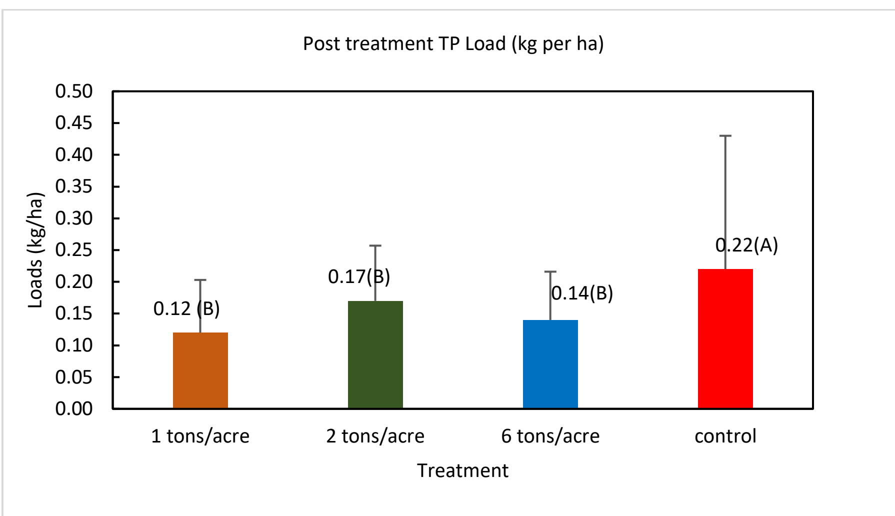

Figure 2 Total Phosphorus (TP) load in surface runoff for gypsum treatments and control during post treatment time. Means with different letters are significantly different at alpha=0.05.

1.1.3. Sulfate results from 1/1/2021 – 9/22/2021

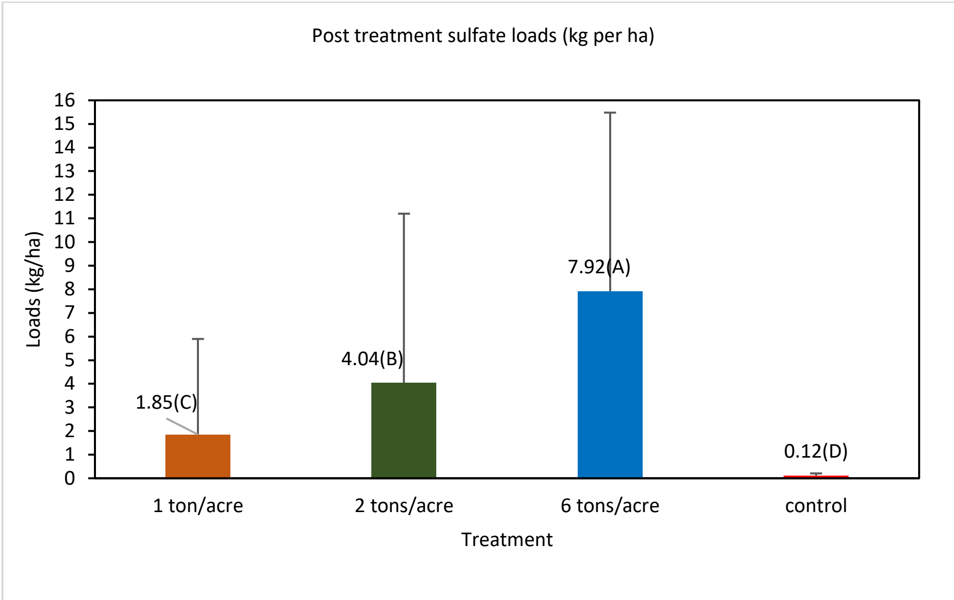

Figure 3 Sulfate load in surface runoff for gypsum treatment and control during the post treatment time. Means with different letters are significantly different at alpha =0.05.

1.1.4. Total Suspended Solids (TSS) Results from 1/1/2021 – 9/22/2021

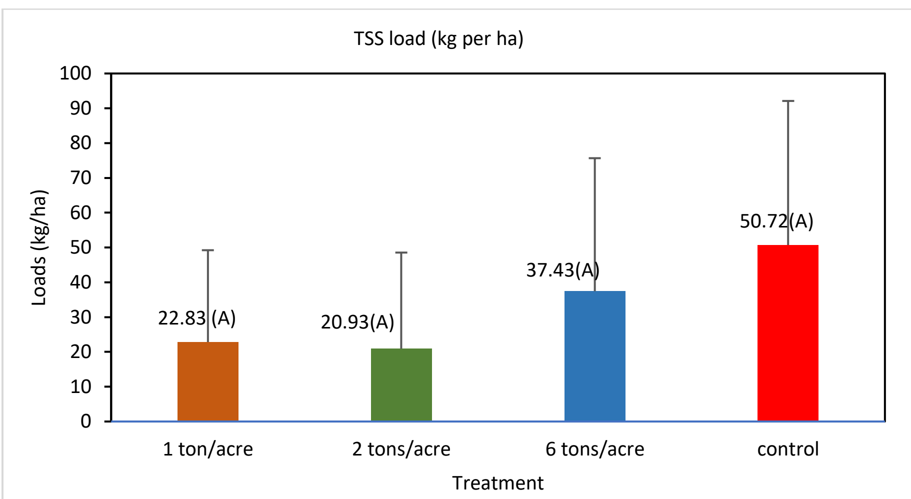

Figure 4 Total Suspended Solids (TSS) loads in surface runoff for gypsum treatment and control during the post treatment time. Means with same letters are not significantly different at alpha = 0.05.

Table 1 Comparison of DRP, TP, Sulfate and TSS Loads between Post Treatment and Pre-Treatment.

Parameter	Treatments	Pre-Treatment Loads kg/ha (2020)	Post Treatment Loads kg/ha (2021)	Change (%)
Dissolved Reactive Phosphorus (DRP)	1 ton/acre	0.14	0.07	50
	2 tons/acre	0.15	0.12	20
	6 tons/acre	0.12	0.08	33.33
	control	0.16	0.11	31.25
Total Phosphorus (TP)	1 ton/acre	0.20	0.12	40
	2 tons/acre	0.17	0.17	0
	6 tons/acre	0.16	0.14	12.5
	control	0.18	0.22	-22.22*
Sulfate (S)	1 ton/acre	0.06	1.85	-2983.33*
	2 tons/acre	0.07	4.04	-5671.42*
	6 tons/acre	0.16	7.92	-4850*
	control	0.06	0.12	-100*
Total Suspended Solids (TSS)	1 ton/acre	141.30	22.83	83.84
	2 tons/acre	144.30	20.93	85.49
	6 tons/acre	173.40	37.43	78.41
	control	168.70	50.72	69.93
Negative values denote increases in export in post-treatment period compared to pre-treatment period, while positive values denote decreases in export in the post-treatment period compared to pre-treatment period.				

Table 2 Comparison between Gypsum Treatment loads and Control Treatment loads for DRP, TP, S, and TSS.

Parameter	**Treatments**	**Post Treatment Load (kg/ha)**	**Control Load(kg/ha)**	**Difference between treatment and control (%)**
Dissolved Reactive Phosphorus (DRP)	1 ton/acre	0.07	0.11	36.36
	2 tons/acre	0.12		-9.09
	6 tons/acre	0.08		27.27
Total Phosphorus (TP)	1 ton/acre	0.12	0.22	45.45
	2 tons/acre	0.17		22.72
	6 tons/acre	0.14		36.36
Sulfate (S)	1 tons/acre	1.85	0.12	-1441.66
	2 tons/acre	4.04		-3266.66
	6 tons/acre	7.92		-6500
Total Suspended Solids (TSS)	1 tons/acre	22.83	50.72	54.98
	2 tons/acre	20.93		58.73
	6 tons/acre	37.43		26.20

Negative values denote % increase while all positive values denote % decrease in treatment plots compared to control.

1.2. DISCUSSION

Based on the results, DRP loads in surface runoff in post-treatment compared to pre-treatment were reduced by 50%, 20% and 33% in treatments 1 ton gypsum per acre, 2 tons gypsum per acre and 6 tons gypsum per acre, respectively. Similarly, TP loads in surface runoff in post-treatment in comparison to pre-treatment have reduced by 40%, 0% and 12.5% in treatment 1 ton gypsum per acre, 2 tons gypsum per acre and 6 tons gypsum per acre, respectively (Table 1). It is likely that calcium sulfate dissociation in gypsum bound to soluble phosphorus, transforming the readily soluble DRP to less soluble calcium phosphate which remained in the soil for a lengthier time. This could explain the reduced DRP losses in surface runoff following treatment.

Total Suspended Solids (TSS) in post treatment compared to pre-treatment has decreased by 83%, 85% and 78% in treatments in 1 ton gypsum per acre, 2 tons gypsum per acre and 6 tons gypsum per acre, respectively. As expected, sulfate has increased post treatment by 2983%, 5671% and 4850 % in treatments 1 ton gypsum per acre, 2 tons gypsum per acre and 6 tons gypsum per acre respectively. Sulfate in gypsum dissociates and thus can be transported in surface runoff.

2. Objective 2: To determine the impact of FGD gypsum applications on crop production

To meet this objective, yield data has been collected from 2018-2021 from 3 farm level sites located at Kinmundy IL, St. Claire County IL and SIU University Farms. Soybean yield data were collected from years 2018 and 2020 and corn yield data were collected from years 2019 and 2021.

2.1. Results

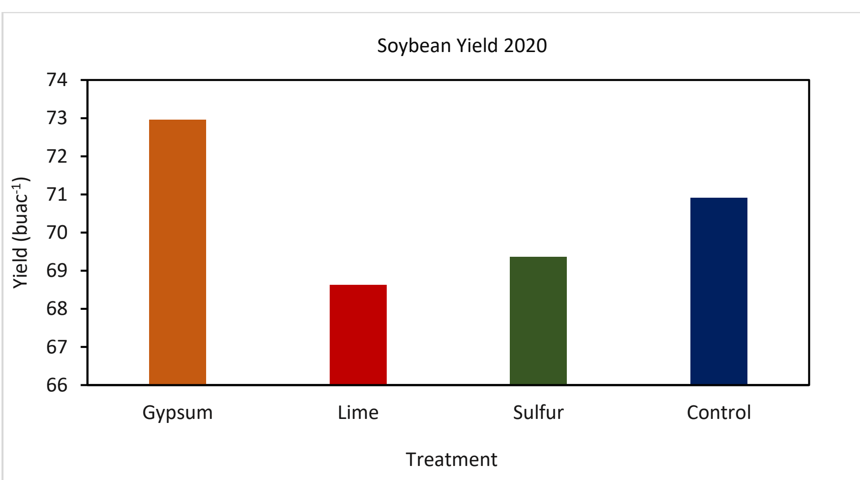

Figure 5 Mean Soybean Yield Values from St. Clair County and Kinmundy yield sites during Fall 2020

According to the fall 2020 yield results, we observed that Gypsum treatment (72.95 bushels per acre) had the highest yield followed by control (70.90 bushels per acre), sulfur (69.30 bushels per acre) and lime (68.62 bushels per acre) treatments.

In addition, soil samples have been collected to assess impacts of FGD gypsum on soil chemical properties and soil physical properties as these properties are highly related to crop production. Soil samples from 2018, 2019, 2020 and 2021 were collected and sent to Brookside Laboratories for analysis of the impacts of treatments on soil chemical properties. Laboratory results until 2020 have been received and 2021 is in progress. Soil samples to analyze physical properties such as bulk density and aggregate stability are collected and were analyzed at SIU, Department of Forestry Soil Lab. Additionally, other soil physical property tests such as water infiltration, soil penetration resistance and soil moisture have been completed. We plan to accomplish data analysis for soil data by February 2022.

3. Objective 3: To conduct economic analysis (partial budget analysis) on the application of FGD Gypsum for farm level yield sites

Economic assessment and sensitivity analysis has been partially completed under the expertise of Dr. Dwight R. Sanders, Professor, Agribusiness Economics at Southern Illinois University. Analysis was done based on data acquired from the beginning of the project until 2020 to evaluate economic efficiency of field application of gypsum by utilizing cost of gypsum. Additionally, gypsum's transportation and application cost, 2018 - 2020 yield values from treatment (Lime, Sulfur, Gypsum, Control) applied farms, and Dissolved Reactive Phosphorus (DRP)and Total Phosphorus (TP) loads in runoff from gypsum applied plots were utilized.

In summary, it has been found that the application of 1 ton of gypsum per acre on alternate year basis to a standard corn-soybean rotation in Southern Illinois reduced phosphorus loads by 2.19 to 3.29 pounds per acre per year compared to the control. The cost per pound of phosphorus removed averages $2.98 per pound across the study. This is economically efficient when compared to most estimates published in the literature. If similar reductions in loading can be obtained with less frequent applications, then the removal costs quickly decline to very attractive levels of under $2.00 per pound of phosphorus.

4. Objective 4: To assess the probability of heavy metal toxicity post FGD Gypsum application in farm sites

One of the major concerns for farmers, landowners and conservationists regarding gypsum application is heavy metals contamination, which can cause serious human health and environmental concerns. Despite having chemical composition like mined gypsum, FGD gypsum has potential for higher concentrations of some trace elements like Arsenic (As), Barium (Ba), Mercury (Hg), Zinc (Zn), Lead (Pb).

To assess heavy metal impacts of gypsum application in soil, heavy metal analysis of soil samples was completed following each gypsum treatment. To fulfill this objective, soil samples were collected and analyzed for heavy metal analysis pre and post gypsum treatment in 2018 (pretreatment), 2019 (post treatment) and 2021 (post treatment) to assess whether traces of heavy metals were observed in soil. In this annual report we have included comparison on mean concentration values of trace elements in soil of depth 0-15 cm pre and post FGD Gypsum application from 2018 and 2021 respectively along with heavy metals' USEPA standards.

4.1. **Result**

Table 3 Mean concentration values of trace elements in (kg/ha) in the soil (0-15 cm) pre and post flue gas desulfurization (FGD) gypsum application, including USEPA standards.

Trace Elements (kg/ha)	EPA Standard (kg/ha)	Control			Gyp 2.24 Mg/ha			Gyp 4.48 Mg/ha			Gyp 13.45 Mg/ha		
		Pre-Treatment 2018	Post Treatment 2019	Post Treatment 2021	Pre-Treatment 2018	Post Treatment 2019	Post Treatment 2021	Pre-Treatment 2018	Post Treatment 2019	Post Treatment (2021)	Pre-Treatment 2018	Post Treatment (2019)	Post Treatment (2021)
Arsenic	41	11.83	18.56	7.56	12.49	17.81	8.25	11.78	17.27	7.85	12.36	18.07	8.34
Copper	1500	22.33	21.84	10.39	29.32	20.09	19.12	21.25	19.89	10.31	22.27	20.92	10.69
Cadmium	39	ND	1.07	1.27	ND	1.05	1.23	ND	1.03	1.21	ND	1.04	1.30
Mercury	300	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Molybdenum	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nickel	18	42.09	34.07	20.66	64.69	38.96	21.03	39.49	35.84	20.89	44.22	35.23	21.88
Lead	420	36.74	24.59	18.80	35.48	28.12	19.12	32.82	26.23	18.98	35.68	25.75	20.05
Selenium	100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	2800	103.50	91.77	52.21	101.62	100.49	46.69	96.93	88.20	47.47	101.39	91.81	46.64
Chromium	3000	40.49	41.72	17.43	41.96	39.04	17.15	41.99	38.90	17.02	40.79	39.21	18.05

****ND denotes Not Detected**

**** All results are in units (kg/ha) like EPA standard**

4.2. DISCUSSION

When results were compared, it was found that the only metal which was exceeding the EPA standard was Nickel (Ni). However, soil Ni concentration was exceeding standard EPA limit both in the pre-treatment and post-treatment period. This suggests that the gypsum application didn't add Nickel to the soil. Arsenic levels increased from 11.53 in 2018 to 18.56 in 2019, but in post treatment 2021 analysis, arsenic levels in soil post gypsum application decreased and was found to be lower than pre-treatment values in all 4 treatments. Similarly, trace elements' (Arsenic (As) Zinc (Zn), Chromium (Cr), Lead (Pb)and Copper (Cu)) value was lower in recent post treatment 2021 analysis compared to pretreatment heavy metal analysis done in 2018. Based on our analysis, we can say that gypsum has not added to heavy metal contamination in soil.

5. Outreach activities in 2021:

Despite the pandemic, we have been proactively conducting outreach activities

- The project was presented at a virtual poster session hosted by SIU on April 15, 2021.
- The project was highlighted virtually through video presentation and poster at conference conducted by Universities Council on Water Resources (UCOWR) Conference which was held in June 2021. In addition to the formal presentation, graduate students had the opportunity to discuss about the project with several professionals and industry experts at the conference.
- Most importantly, this project was highlighted through oral and poster presentation SIU Ag Field Day, conducted at SIU Farms on July 9, 2021. Farmers, related stakeholders and professionals from the agriculture and natural science industry took part in the program.