Title: Advancing Organic Potato Production with Mustard Seed Meal Extract: a multi-pronged tool to control weeds, promote soil health, and improve potato nutrition.

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1. Project Summary:

Weed management, soil health, and nutritional quality of organically produced foods are among the highest priority of organic research topics according to organic farmers across the US, and abundant peer-reviewed research supports these perspectives. Utilizing innovative organic agricultural practices that improve soil health, combat weeds, and enhance nutritional quality of staple foods will enable farmers to successfully meet the challenges of feeding a rising global population. Our overall goal is to discover effective weed management strategies for organic potato production that promote healthy soils and nutritious potatoes. Our research program has developed a bioherbicide from yellow mustard (*Sinapis alba*) seed meal that can be used in organic crop systems to control for more than a dozen problematic weeds including redroot pigweed, Powell amaranth, and green foxtail. While the application of the mustard bioherbicide reduces the weed density, the broader effect of mustard bioherbicide on soil health still needs to be understood. Thus, the objective of this project was to evaluate the overall effect of mustard based bioherbicide on organic potato production. To demonstrate this, we have conducted greenhouse and field studies at two Northern Idaho organic farms using three different bioherbicide applications. Weed control efficiency of the mustard bioherbicide was compared against the commercially available organic herbicide. We have demonstrated that mustard bioherbicide application results in the overall improvement of soil health and quality of potatoes by increasing the antioxidant activity of tubers. The results obtained provide a critical data for holistic assessment of bioherbicides use in organic systems for short- and long-term sustainability of crop production.

2. Introduction to Topic

Weed management and soil health are the highest priority research topics according to US organic farmers (Jerkins and Ory 2016). Nutritional quality of organic foods was similarly viewed as one of the highest agricultural research priorities. Countless peer-reviewed publications from diverse research disciplines support these farmers' perspectives. Without healthy soils, life on Earth cannot be sustained. This fact is made clear in the Natural Resources Conservation Service definition of soil health: "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans". Organic agroecosystems inherently foster improved soil health, but limited options for combatting weeds can adversely impact soil health (Abbott and Manning 2015). Tillage is widely used for weed management in organic agriculture, but this practice depresses soil health by increasing soil compaction, increasing soil erosion from wind and rain, and disrupting soil microbial communities (Lehnhoff *et al.* 2017; Wang *et al.* 2017). Hand-weeding is also commonly practiced, especially in small organic farms, but this labor-intensive method is often cost-prohibitive to farmers (Getz *et al.* 2008; Carlisle *et al.* 2019). Innovative, effective, and economically and environmentally sustainable weed control strategies are urgently needed not only by organic farmers, but by the entirety of global agriculture, especially in light of the recent international climate change report (Allen *et al.* 2019).

Increasing global human population, coupled with climate change and soil desertification, challenges agriculture to unprecedented extents (Sivakumar 2007; Lal 2008; Rockström *et al.* 2017). To meet the dietary needs of an estimated 9.5-10 billion people by 2050, nutritionally dense staple foods will need to be grown using methods which improve soil health and protect the environment (Foley *et al.* 2011; Goicoechea and Antolín 2017; Roberts and Mattoo 2019). Potato is the third most important food crop worldwide, but it is also a leading crop for pesticide (herbicide?) usage (Dandurand *et al.* 2017). In the US, herbicides are used on 94% of all potatoes. Idaho leads the nation in potato production, but < 1% is grown organically. However, organic potato acreage in Idaho is steadily increasing, illustrating consumer demand and farmer interest. The aim of this project is to promote production of organic fresh market and seed potatoes by providing growers with a multi-pronged agronomic tool that controls weeds, promotes soil health, and improves tuber nutritional qualities. It is hypothesized that concentrated mustard seed meal extract (MSME) is just such a tool.

Mustard seed meal in the non-extracted and nonconcentrated form has demonstrated efficacy as a pre-emergent (Rice *et al.* 2007; Yu and Morishita 2014; Wang *et al.* 2015; Boydston *et al.* 2018) and post-emergent control (Boydston *et al.* 2008, 2011) for more than a dozen problematic weeds including: lambsquarters (Rice *et al.* 2007; Yu and Morishita 2014), redroot pigweed (Rice *et al.* 2007; Boydston *et al.* 2011; Yu and Morishita 2014), chickweed (Rice *et al.* 2007; Boydston *et al.* 2008), crabgrass (Wang *et al.* 2015), kochia (Yu and Morishita 2014), and hairy nightshade (Boydston *et al.* 2018). However, utilization of mustard seed meal for weed control has been hindered by batch-to-batch variability (Morra *et al.* 2018), excessive nitrogen levels

(Rice *et al.* 2007; Snyder *et al.* 2009) and challenging logistics associated with needing large quantities to attain bioherbicideconcentrations (Boydston *et al.* 2011; Morra *et al.* 2018).

Our research program has developed an extract from white mustard (*Sinapis alba*) seed meal that contains consistently high concentrations of the bioherbicidal compound, thus reducing application rates and avoiding nitrogen overload (Popova and Morra 2014; Popova *et al.* 2014, 2017; Morra *et al.* 2018). Our concentrated mustard seed meal extract (MSME) demonstrated pre- and post-emergent control against the weeds Powell amaranth (*Amaranthus powellii*) and green foxtail (*Setaria viridis*), as reported in one greenhouse study (Morra *et al.* 2018). However, no research has been published on the herbicidal efficacy of MSME under field conditions, or in organic systems.

Mustard seed meals in the non-extracted and nonconcentrated form have been shown to enhance soil health, *i.e.*, the capacity of soil to function and provide life-sustaining ecosystem services and improve crop health. These positive effects on soil and plant health arise in large part from changes in the soil microbial community structure and function as a result of soil incorporation of mustard seed meals (Zaccardelli *et al.* 2013; Mazzola *et al.* 2014, 2016). For example, several studies have reported that mustard seed meal treatments resulted in soil microbial communities that enhance suppression of soilborne plant disease (Mazzola *et al.* 2017; Wang and Mazzola 2019a; b). Addition of mustard seed meals also influences the nutrient composition of the soil (Wang *et al.* 2012). The functional ability of soil microorganisms to enhance the nutritional quality of fruits and vegetables is an emerging research topic of critical potential, but one that has been sparsely studied (Goicoechea and Antolín 2017). Moreover, the few published reports on this topic have studied only the potential of arbuscular mycorrhizal fungi, not other soil microbes, to improve food crop nutrient quality (Torres *et al.* 2018, 2019; Tran *et al.* 2019).

This is the first known research project to test the bioherbicidal potential of concentrated MSME in organic farming systems. It is also the first known study to evaluate the influence of MSME on soil health. Moreover, this is the first study to examine the effect of MSME on the human nutritional quality of potatoes, or indeed, of any food crop. In conclusion, the results of this novel multifaceted project will provide a foundation from which additional innovative organic agroecosystem research will develop.

3. Objectives Statement

Our overall goal is to discover effective weed management strategies for organic potato production that promote healthy soils and nutritious potatoes. We will attain this goal through the following four objectives:

Objective 1: Evaluate the efficacy of MSME on inhibiting weed seed germination (preemergence) and killing aboveground growth (postemergence) under field conditions.

Modifications: based on greenhouse data, we have opted to use a combination of post and preemergence MSME application to target weed seed germination as well as already emerged weeds. This approach yielded optimum weed control while maintaining reasonable application rates of MSME. Another modification from the original proposal is the change in the field site. One of the field trials was carried out at the Soil Stewards Farm instead of the Sandpoint Organic Agriculture Center as originally proposed. The change was made due to the logistics associated with the pandemic (health issues, driving, and personnel restrictions). Soil Stewards Farm is a University of Idaho farm managed by the Department of Soil and Water Systems. The farm was founded in 2017 and received certified organic status in 2020.

Objective 2: Determine the influence of MSME application on soil health.

Objective 3: Evaluate the influence of MSME on nutritional quality of potatoes.

Objective 4: Assess the efficacy of MSME to act as a preemergence and postemergence herbicide against common annual broadleaf and grass weed species under greenhouse conditions.

4. Materials and Methods:

Materials and supplies

Mustard seed meal extract (MSME) was prepared using the procedure described previously from OMRI certified *S. alba* (IdaGold variety) seed meal (Farm Fuel Inc., Watsonville, CA) (Morra *et al.* 2020). Certified Organic Yukon Gold seed potatoes were purchased from New Sprout Farms (Asheville, NC). Seeds of barnyard grass (*Echinochloa crus-galli)* and common lambs quarters *(Chenopodium album)* were obtained from Companion Plants Inc. (Athens, OH, USA).

Greenhouse weed trials

The greenhouse trials were conducted at the Sixth Street Greenhouse at the University of Idaho in Moscow, ID. For *preemergence trials*, twenty pots (4 in^3) were filled with OMRI-listed soil and applied with MSME directly onto the surface of the soil at 0, 2.5, 4.9, and 7.4 t ha^{-1} rates. The MSME was applied by creating a solution and spraying it onto the plant and soil surface. Pots were kept in a greenhouse with a 14.5-h day length and maintained at 32/19 °C maximum/minimum temperatures. Soil was maintained moist by watering every other day using a lightly sprinkling hose attachment. The pots were then arranged in a randomized design, and 25 seeds were planted 2 mm deep in each pot. Emerged live seedlings were recorded at 7, 14, and 21 days after treatment (DAT). Percent weed control was visually rated at 14 and 21 DAT on a scale of 0% = no injury to 100% = dead. At 21 DAT, all plants were cut off at the soil surface, oven dried at 60 °C, and final dry biomass was determined. Three individual trials were conducted for each weed species.

Postemergence trials for both weed species were conducted in 4 in^3 pots were filled with the OMRI-listed potting soil. The pots were arranged in a randomized design. Twenty-five seeds for each weed species were planted 2 mm deep into each pot. After emergence, plants were thinned to five uniform seedlings per pot. When plants were at the 4-leaf stage (~6-8 cm tall) they were treated with MSME at 0, 2.5, 4.9, and 7.4 t ha^{-1} application rate using the methodology described for the preemergence trials. Number of live plants per pot and visual percent weed control were recorded on a scale of 0% = no injury to 100% = dead at 7 and 14 DAT. At 14 DAT, average plant height was recorded, and all plants were cut off at the soil surface, oven dried at 60 ℃, and the final dry biomass was determined. Three individual trials were conducted for each weed specie.

Field trials

The potato field trials were conducted on two certified organic farms in Northern Idaho: Soil Stewards (SS) Organic farm (Moscow, ID) and Pokey Creek (PC) farm (Saint Maries, ID) (Fig. 1). SS farm is a University of Idaho farm managed by the Department of Soil and Water Systems. The farm was founded in 2017 and received certified organic status in 2020. SS farm produces vegetables on approximately 0.25 to 0.5 of its 4 acres. SS farm has silty clay loam Mollisolls from two soil series: Latahco (Argiaquic Xeric Argialbolls) and Thatune (Oxyaquic Argixerolls). Moscow, ID receives an average of 69 cm of rain and 124 cm of snow annually and has an annual average temperature of 8.3 °C (U.S. Climate Data, 2018). PC farm is a 4.5-acre farm located along the St. Joe River in St. Maries, ID. The farm has been certified organic since 2013, but it has been farmed for more than 20 years. PC farm produces a wide array of produce including beets, lettuce, cauliflower, tomatoes, cabbage, lettuce, spinach, onions, peppers, potatoes, garlic seed, and more. PC farm has silt loam Inceptisols soil from Miesen soil series (Vitrandic Humudepts). St. Maries, ID has an average annual temperature of 8.7 °C and receives an average of 78 cm rain and 142 cm of snow each year. Twenty-five plots (90×60 cm^2) were randomly assigned in one long row with a 30×60 cm^2 buffer zone. Within each experimental plot, four seed potatoes were planted. At SS farm, the potato row was watered via drip irrigation at a rate of 1 inch per week. At PC farm, potato plots were watered overhead with a large sprinkler. Three weeks after planting, plots at both farms received the following treatment: MSME (4.5 t ha^{-1}) was applied once (Plot A), twice with a two-week interval (Plot B), or three times with a two-week interval (Plot C). Untreated control (Plot X) received no MSME. Plots H received a treatment of the OMRI certified herbicide Suppress® by mixing a 9 % solution (12 fl oz Suppress® in 1 Gal of water) in a manual-pump weed-sprayer and dousing all

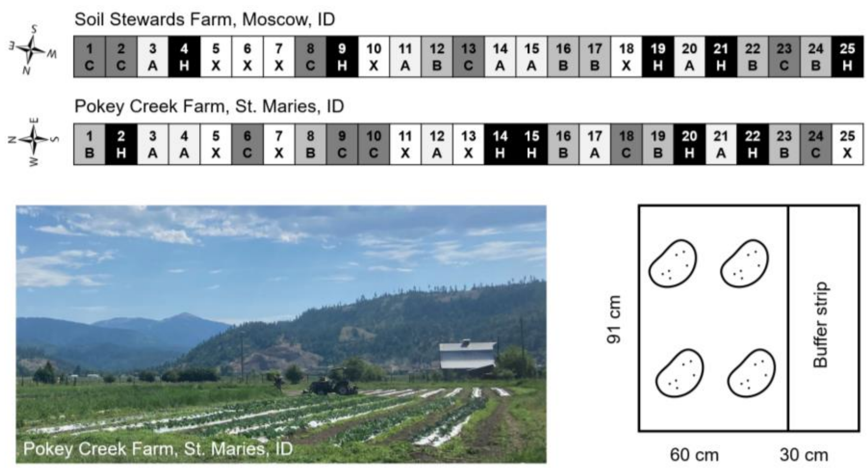

Figure 1. Set up of field plots at Soil Steward Farm (Moscow, ID) and Pokey Creek Farm (St. Maries, ID). Five field replicates for four treatments (control soil (X) and soil amended with mustard seed meal extract once (A), twice (B), or three times (C)) were randomly assigned. Four potatoes were planted per 3×2 ft^2 plot with 3×1 ft^2 buffer.

weeds in the plot until fully covered. One week after treatment, all the weeds in each plot were then cut at the soil surface, oven dried at 60 °C, and the final dry weight was recorded.

Soil analysis

Soil from 0-15 cm of each plot was collected prior to the application and on the day of potato harvest. Soil pH, soil macro and micronutrients, and Haney soil health score analysis were conducted at Ward Laboratories, Inc (Kearney, NE, USA). Soil sulfate was quantified using the procedure previously developed in our laboratory (Popova and Morra 2014).

Plant analysis

Potato tubers were harvested, weighted to determine the yield, and visually evaluated for quality appearance. After that, potatoes were freeze-dried, and analyzed for phenolics, antinutrients, and starch contents. Phenolics and antinutrient contents were evaluated as described previously using HPLC/MS method (Shakya and Navarre 2008; Navarre *et al.* 2011) Corresponding antioxidant activity of potato extracts was assessed using Folin–Ciocalteu assay (Albishi *et al.* 2013). Total starch content of potatoes was measured using Megazyme® Total Starch Assay Kit.

Data analyses

Data were analyzed by analysis of variance (ANOVA) using JASP (University of Amsterdam, Amsterdam, The Netherlands), a graphical open-source graphical software package for basic statistical procedures (Love *et al.* 2019). Pairwise comparisons were performed using Student's t-test to assess the treatment differences and means were considered significantly different at $P \leq 0.05$.

5. Project Results:

Objective 1: Evaluate the efficacy of MSME on inhibiting weed seed germination and killing aboveground growth under field conditions.

The major weeds found on the SS farm plots were Canada thistle (*Cirsium arvense*), field bindweed (*Convolvulus arvensis*), and dandelion (*Taraxacum*). The Canada thistle and field bindweed were especially abundant and accounted for most of the biomass collected. After the first application of MSME, the weed biomass increased relative to the control plot (Fig. 2). Since the amount of weed seeds in soil and the germination efficiency was not known in the used plots, this effect can be coincidental or associated with the additional input of nutrients from MSME. MSME contains 2.1 % of total nitrogen by weight in the form of labile proteins and other organic compounds. This additional nitrogen could be absorbed by weed plants and provide a stimulus for growth. By the time of the second application, the weed biomass in control plots was close to the weed biomass of plots treated with MSME once and two times. Addition of MSME three times over the growth season did not provide a desired weed control. It is of note that the application of OMRI-certified herbicide, Suppress®, did significantly lower the dry biomass of weeds when compared to the control or MSME.

The major weeds found on the PC farm plots were Canada thistle, lamb's quarters (*C. album*), and field horsetail (*Equisetum*). PC farm had richer soil with high organic carbon content and a more favorable water regime which resulted in faster potato plant growth. Once potato plants emerged, they provide a thick canopy which minimized the weed growth. The first application of MSME resulted in a reduced weed biomass (Fig. 2). Unlike the SS farm trial, there were no spikes in weed growth promoted by MSME application. This can be due to the differences in weed species as well as soil conditions at the two farms. While the reduction in weed biomass after the application of MSME was not statistically lower than in the control plots, the long-term effect was observed. Plots treated with MSME had consistently lower weed biomass even three weeks after the application. However, after three weeks, MSME needs to be re-applied. The efficiency of MSME was comparable with the Suppress® herbicide.

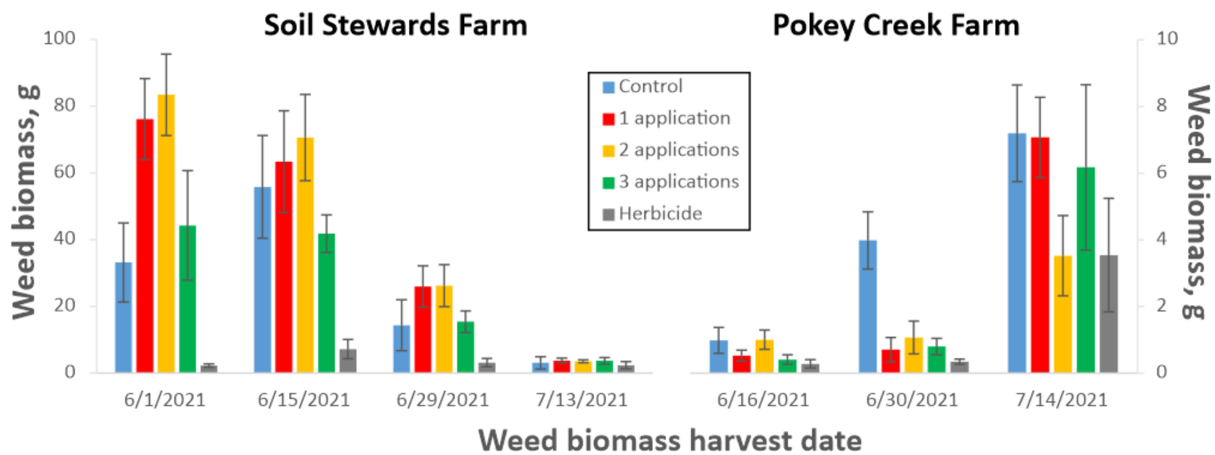

Figure 2. The average dry weed biomass per plot for each group: X (control), H (Suppress Herbicide), A (one MSME application), B (two MSME applications), and C (three MSME applications).

<u>Objective 2:</u> Determine the influence of MSME application on soil health.

In both farms, the application of MSME did not significantly affect the microbial active carbon (Table 1). Microbial active carbon is the living component of the soil organic matter pool and is a sensitive indicator to the microbial community as a whole; even in short-term studies (Alvarez and Alvarez 2000). At the same time, soil respiration increased in the soils treated with MSME at SS and PC farms. Soil respiration at SS farm increased from an average of 81.6 to 131.8 ppm carbon. However, the difference was not statistically significant. In PC farm, two and three applications of MSME resulted in a significant increase of soil respiration from 174.0 to 277.8 and 310.2 ppm carbon, respectively.

Table 1. Microbial indicators in control (X) and soil amended with MSME once (A), twice (B), or three times (C) at two certified organic potato farms.

Plot	Soil respiration	% MAC	Organic C:N
		Pokey Creek	
X	174±47	186±44	8.0±0.5
A	221±28	219±76	6.9±1.4
B	278±57	266±54	6.1±0.8
C	310±46	265±67	5.5±0.5
		Soil Stewards	
X	82±18	51±12	6.4±0.4
A	87±17	45±7	6.2±0.5
B	106±11	52±4	5.9±0.6
C	132±15	48±15	5.9±0.8

The ratio of organic carbon to organic nitrogen was used to measure the balanced soil organic composition, which is an important indicator of healthy microbial functions (Table 1). Baseline C:N ratio falls in average soil microbe ratios for both farms. At PC farm, the baseline C:N ratio was 8.0, which decreased to 5.5 after three additions of mustard seed meal extract. At SS farm, the baseline C:N ratio was 6.4. Similarly, to PC farm soils, the C:N ratio steadily decreased with each additional application. However, the change was not statistically significant.

Mineralization of nitrogen to plant-available inorganic forms of nitrogen was reflected by the ammonium and nitrate concentrations detected in the soil. Total inorganic nitrogen content in both farms significantly increased with the application of MSME and accounted for 27.1 and 107.8 ppm of nitrogen after three MSME applications for PC and SS farms, respectively. For PC farm, the increase was mostly driven by the increase in nitrate concentrations (from 6.2 to 24.2 ppm), while ammonium concentrations increased at a slower rate (from 1.7 to 3.0 ppm). For SS farm, the predominant contribution in total inorganic nitrogen was due to the accumulation of ammonium (from 5.0 to 58.3 ppm) with nitrate less affected (from 36.9 to 49.6 ppm).

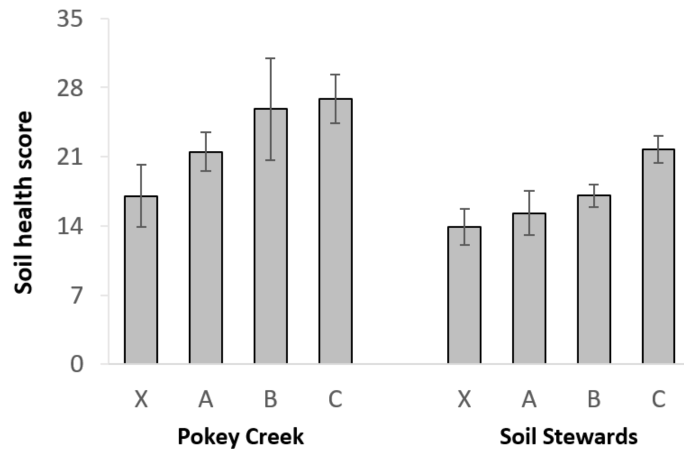

Figure 3. Soil health score in control soil (X) and soil amended with mustard seed meal extract once (A), twice (B), or three times (C) at two certified organic potato farms.

For assessing soil quality, the Haney soil health test was used with the calculated soil health scores used as a quantifiable measure (Fig. 3) (Haney *et al.* 2010). The soil health score is based on soil respiration and the amount of water extractable organic carbon and nitrogen. Baseline soil health scores in SS and PC farms were 13.90 and 17.02, respectively. These scores fall in the range for cultivated soils. Generally, soil health scores range anywhere from 0 to 50, with higher numbers representing better soil conditions. Soils with scores >7 are considered acceptable for agricultural soils, while native grasslands can have scores as high as 100 (Haney *et al.* 2018). Generally, soils that have low baseline scores would require more extensive management. The soil health scores are consistent with the assessment of soil quality at both farms. With the addition of MSME, the soil health index at SS and PC farms increased up to 21.74 and 26.86, respectively. While the soil health index represents an arbitrary number, there is a clear indication of overall soil function improvement with the application of mustard seed meal extract likely due to increased soil respiration and increased available N.

Objective 3: Evaluate the influence of MSME on nutritional quality of potatoes.

The effect of MSME application on potatoes was evaluated based on yield, starch content, antioxidant activity, and the concentrations of phenolics present in tubers from SS farm (Table 2). Potato yields, even though not statistically significant, were generally lower for MSME treated potatoes. Starch content was not significantly affected by MSME application and ranged from 52 to 58 g/100 g of potatoes on dry weight basis. The application of MSME had a positive effect on the overall antioxidant content in potatoes. For example, one time application of MSME to potatoes resulted in more than a two-fold increase in antioxidant content of tubers. Every additional application of MSME increased the antioxidant content by ~1.5 times (Table 2). This increase can be explained in terms of phenolic compounds that increased in MSME treated plots. Specifically, berberine and 3,4-dihydroxycinnamic acid increased up to 3.5 and 1.6 times after MSME application. While the increase in glycoalkaloids that are considered antinutrients had been observed in MSME treated potatoes, the increase was not statistically significant. Overall, there was no indication of any negative effects of MSME on nutritional properties of potatoes.

Table 2. Yields and selected nutritional qualities of potatoes harvested at Soil Stewards Farm (Moscow, ID).

	Control	1 application	2 applications	3 applications
Potato yields, g	948±273	475±322	139±363	315±389
Starch, g/100g	57.1±0.9	52.0±2.7	53.6±2.2	52.2±3.5
Antioxidant content, mg/g	0.6±0.1	1.6±0.3	2.6±0.8	3.3±0.9
Phenolics conc., mg/g				
Saponine	0.17±0.01	0.15±0.02	0.16±0.0	0.16±0.02
Barberine	5.1±2.1	9.1±3.6	13.9±5.8	16.5±11.2
3,4-Dihydroxycinnamic acid	2.7±0.4	4.1±0.7	4.1±0.5	3.6±2.0
Rutin	0.16±0.10	0.15±0.04	0.12±0.05	0.31±0.29
Abscisic acid	0.027±0.007	0.033±0.009	0.033±0.005	0.026±0.013
Antinutrients conc., mg/g				
Solanine	0.80	1.15±0.13	0.78±0.44	1.06±0.43
Chaconine	2.66	3.52±0.25	3.67±0.26	3.84±0.49

Objective 4: Assess the efficacy of MSME to act as a preemergence and postemergence herbicide against common annual broadleaf and grass weed species under greenhouse conditions.

Preemergence trials of MSME had a pronounced herbicidal effect on both tested weed species, *C. album* and *E. crus-galli* (Fig. 4). For *C. album*, the mean number of emerging seeds 7 days after sowing (DAS) was lower in MSME applied pots by 1.4-8 times. Similar trends were observed at 14 and 21 DAS with less weeds emerging in MSME treated soils. For example, application of 7.4 t ha^{-1} of extract, reduced the number of emerged seed in a half in Trials 1 and 2 and more than 40 times in Trial 3. For all three trials, the data were consistent with the higher application rates resulting in better weed control. However, a variability among trials was high, and when data from three trials were combined, treatments with MSME were not statistically different from control pots. The effect of MSME in this case of *E. crus-galli* was less prominent than in the case of *C. album*. Specifically, while the application of MSME had an herbicidal effect on *E. crus-galli*, the number of emerging plants has steadily increased over two weeks.

Application of MSME did not only reduce the emergence, but also affected the biomass of emerged weeds (Fig. 4). Plant biomass collected 21 DAS was lower in plots treated with mustard extract, and generally declined with the increase in mustard extract application rates for all three trials. The effect was stronger for *C. album* than for *E. crus-galli*. MSME did not significantly reduce the number of live *E. crus-galli* plants 21 days after preemergence treatment nor the final dry weight, and the percent weed control was not significantly affected.

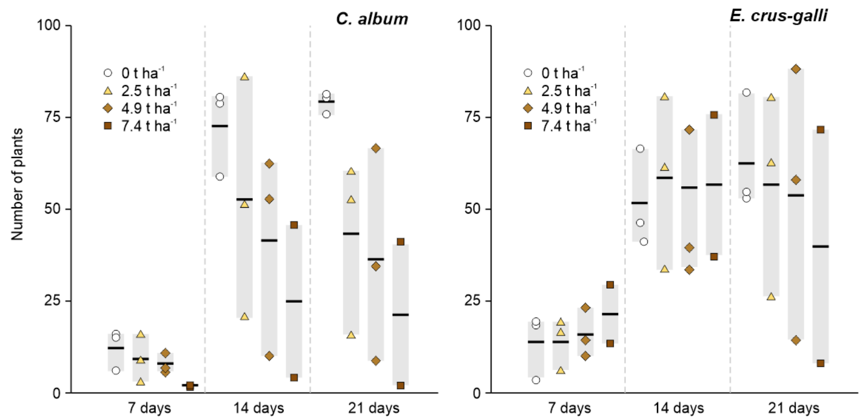

Figure 4. Pre-emerge application of mustard extract under greenhouse conditions. Data are present as averages of three individual trials with standard error for the combined data.

In *postemergence trials*, MSME did significantly reduce average plant height of *C. album* plants 14 DAT, and percent control did significantly increase with higher application rates. MSME did appear to reduce the average dry weight of *C. album* plants 21 DAT, however the results were just barely not significant. Similar to the *C. album* results, as the application rate of MSME increased, the average plant height of *E. crus-galli* significantly decreased. MSME applications also reduced the dry weight of *E. crus-galli* 14 DAT, although not statistically significant, and visual weed control significantly increased 7 DAT and 14 DAT, especially in Trial 3. *S. alba* MSME demonstrated statistically significant efficacy in postemergence control trials of *C. album* and *E. crus-galli* weeds at application rates of 2.5, 4.9, and 7.4 t ha^{-1}. The herbicidal effect of the MSME was most apparent by evaluation of plant dry weight, where an increase in application rate consistently caused a decrease in plant dry weight.

6. Conclusions and Discussion:

Based on the results obtained from the greenhouse study, MSME is effective as a bioherbicide in inhibiting weed seed germination and killing aboveground growth of broadleaf and grassy weeds. MSME is more effective in preemergence weed control than in postemergence and is more effective on broadleaf weeds than grassy weeds. Although 7.4 t ha^{-1} was the most successful at controlling weeds, a MSME application rate of 4.9 t ha^{-1} was effective in controlling weeds while maintaining a low enough application rate to be logistically viable.

Results from the greenhouse study suggest that the most effective MSME weed control strategy is to apply MSME to young seedlings right after they have emerged. Another useful strategy is to apply the MSME after an initial weed control or suppression operation is performed, like tilling. This way, the MSME can kill any remaining seedlings and stop seeds from germinating or inhibit seedling growth. Overall, the MSME was more effective in controlling *C. album* (a broadleaf weed) than *E. crus-galli* (a grassy weed) which is consitant with previous research (Boydston study). This was true across the board with preemergence and postemergence trials; *C. album* treated with MSME sprouted fewer live plants, sustained higher percent control and recorded less dry weight than *E. crus-galli*. This is important information to know if farmers are to eventually include MSME applications in their weed control strategy.

As compared to the greenhouse study, the efficacy of MSME for the control of weeds in the field trials was less evident. At PC farm, the plots that were treated with MSME appeared to have less lamb's quarters weeds present, but it did not seem to affect the growth of rhizomatous weeds like Canada thistle and field horsetail. Most of the problematic weeds at SS farm were rhizomatous weeds that did not appear to be very affected by the MSME. The discrepancy between the greenhouse study and the field trial is likely due to the prevalence of Canada thistle and field bindweed in the field. Rhizomatous weeds are generally harder to control and the potential of MSME was not assessed on these two weeds in the greenhouse. Specifically, field bindweed has high rates of regrowth from the rhizome, while Canada thistle has a rather deep and extensive root system.

At the same time, the use of MSME had a significant positive effect on overall soil conditions. Increases in soil respiration suggest a boost in microbial population and, consequently, high rates of residue breakdown (Nair *et al.* 2012). The high turnover rates can result in a substantial nitrogen fertilizer reduction due to the higher availability of inorganic nitrogen. The observed effects are consistent with predominantly labile carbon composition of MSME. The higher turnover rates in the soil where MSME was applied are generally beneficial for plant growth and nutrient availability (Friedel *et al.* 2001). The results are consistent with the previous studies for application of organic amendments, including mustard seed meals. Specifically, it has previously been found that mustard meal increases respiration in soils over several years, thus demonstrating an overall positive effect on soil health (Lulu and Insam 2000).

The discrepancies between the two farms in the extent of the MSME effect on soil health can be explained in terms of different soil types and management practices. When the ratio of organic to inorganic nitrogen was calculated for both farms, similar trends were observed with the ratio declining with the application of MSME. The decline was not statistically significant but reflected the superposition of two trends with regards to organic and inorganic nitrogen. While the increase in inorganic nitrogen is favorable for the short-term plant nutrient needs, the accumulation of organic nitrogen in soils by diversifying nitrogen pools is considered a better strategy for long-term soil health (Koch *et al.* 2020). Multiple applications of MSME can help maintain an adequate nitrogen supply for plants over the growth season while also reducing the risk of nitrogen leaching. Organic nitrogen release, as calculated from the C:N ratio, organic nitrogen concentrations, and soil respiration, increased significantly with mustard seed meal extract application. This demonstrates the potential to boost the plant available nitrogen surplus, and consequently, productivity of soils.

To the best of our knowledge, this is the first comprehensive evaluation of soil health changes induced by the addition of MSME. It is also one of the few studies on soil health in small farm organic potato production in Northern Idaho. While soil health tests, such as the Haney test, have been used in the midwestern United States, the utility of such tests to other agricultural regions is still under development (Singh *et al.* 2020). However, under the scope of this field study at two certified organic farms, we have clearly demonstrated that the increase in the Haney health score is consistent with the management practice of adding MSME. Moreover, the data obtained for organic and inorganic soil constituents demonstrate the benefits of MSME application for improving soil quality.

The use of MSME did not have any negative impacts on yields, quality of potatoes, nor starch content. Antioxidant activity of potato extracts was increased in potatoes from the plots treated with MSME, likely due to the improved soil conditions and the input of nitrogen from MSME.

This research provided the groundwork for using MSME as a bioherbicide in organic farming systems. Additional research on which other crops are resilient enough to withstand the MSME would be useful for determining future use applications. Other crops that might be more resilient to MSME would have a more powerful future use case paired with MSME as an organic bioherbicide. More research needs to be done on whether MSME can control different types of weeds, particularly rhizomatous weeds like Canada Thistle, field horsetail and field bindweed.

7. Outreach:

Due to the COVID restrictions, outreach activities were limited. Nevertheless, we were providing the outreach in the following forms. We provided feedback to producers that collaborated on the project and addressed all their questions and concerns regarding the project. The results of the project were also shared with other producers through personal communication. Current research project was highlighted on the University of Idaho website. We anticipate carrying out additional outreach regarding the results obtained during the Summer 2022 during a Farmers' Market and the University of Idaho Field day. To reach out the scientific community, we have prepared a talk for the American Chemical Society Spring 2022 Meeting (March 20-24th, 2022) in Agricultural and Food Chemistry sections. Two manuscripts were prepared with the results from the current project. One manuscript has already been submitted for publications. The second project is in preparation. We have also communicated the results of the study with our industrial partner for MSME commercialization.

8. Financial accounting:

Please see the report attached.

9. Leveraged resources:

No additional funding was currently acquired to continue the project. However, the presented data will be used for applying for USDA NIFA funds during Summer to continue and expand the work.

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11. Photos and other addenda:
Greenhouse Weed Control Trials

Figure 1A. Trial 1 of the postemergence application for *C. album* (lower group of pots) and *E. crus-galli* (upper group of pots).

Field Weed Control Trials

Before

After

Figure 2A. An example of one experimental plot at the Soil Stewards Farm (plot 15A) before and after the first application of MSME. The MSME has been applied to the top 1 ft and bottom 1 ft of the plot and watered to incorporate it into the soil. The middle 1 ft is not included in the data and is hand weeded.

Figure 3A. Pokey Creek Farm plot layout. Plots were 3 ft x 2 ft along the top of the potato row, with 1 ft x 2 ft buffer zones between each plot.

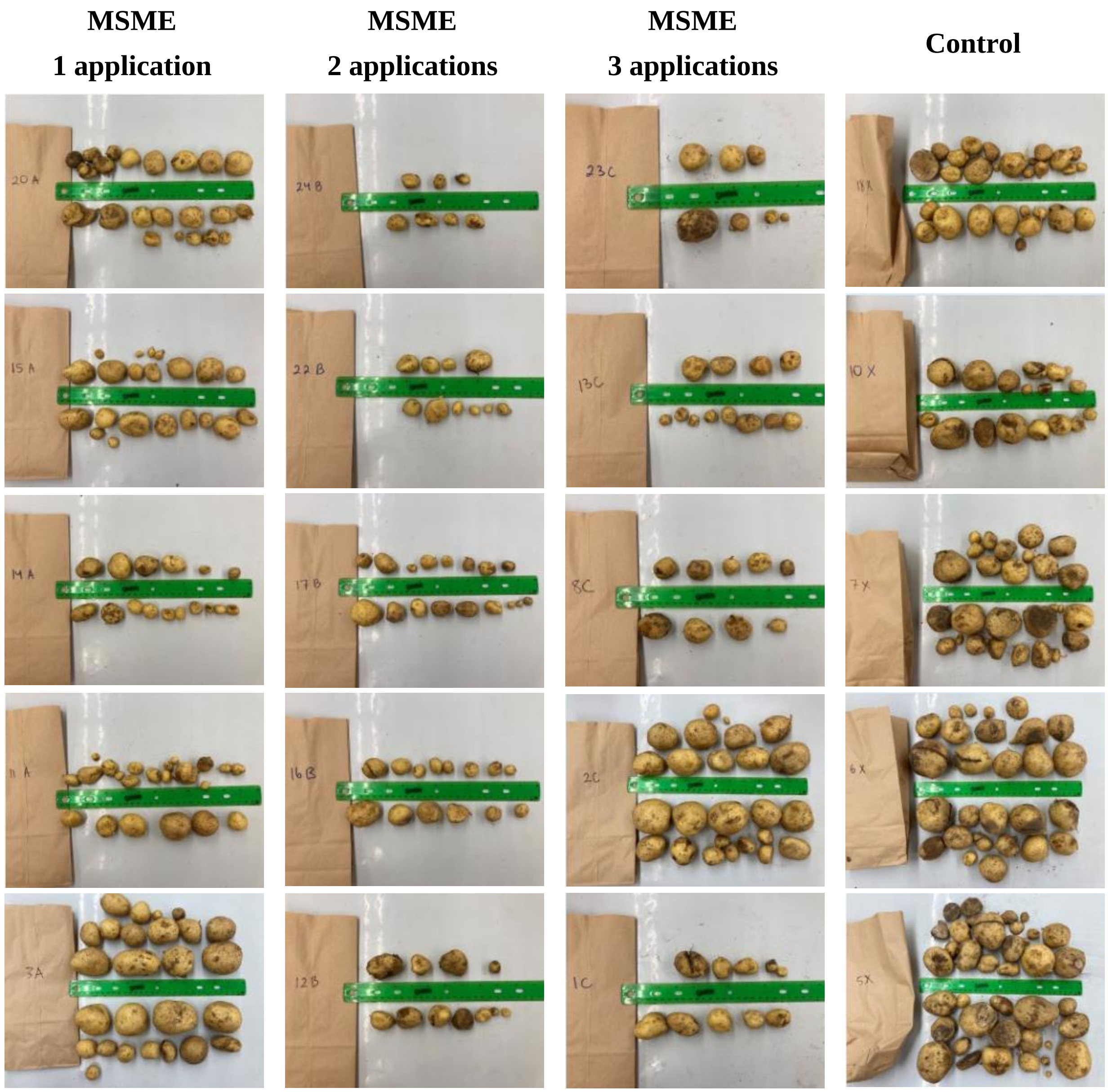

Figure 4A. Potatoes harvested from Soil Stewards Farm after 1, 2, and 3 applications of MSME.

ACS Spring 2022 - 2nd Scheduling Notice [3652540](UPDATED)

ACS Spring 2022 <onbehalfof@abstractcentral.com>
Tue 3/1/2022 5:34 PM
To: Popova, Inna (ipopova@uidaho.edu) <ipopova@uidaho.edu>

Dear Dr. Inna Popova,

Your presentation has been scheduled for the technical program of ACS Spring 2022, March 20-24, 2022.

Please make note of the dates, times and locations, as they may have changed from previous notices as a result of withdrawals and program changes.

PAPER ID: 3652540
PAPER TITLE: The use of mustard bioherbicide in organic potato production: weed control, soil health, and crop quality
DIVISION: Division of Agricultural and Food Chemistry
SESSION: General Papers
SESSION TIME: 10:00 AM - 2:00 PM

PRESENTATION FORMAT: Oral - Virtual
DAY & TIME OF PRESENTATION: Tuesday, March 22, 2022 from 11:35 AM - 11:55 AM
ROOM & LOCATION: Zoom Room 1 - Virtual Room

Registration
In order to make your presentation you must be registered for ACS Spring 2022. Registration for the meeting is open. If you have not yet registered, please do so as soon as possible. Please see the ACS Spring 2022 meeting website for complete information on the meeting.

If you are unable to attend your scheduled live session, there are additional opportunities to share your work with meeting attendees.
• Provide a pre-recorded talk in advance to the presider or organizer(s) of the virtual session to play during your presentation time.
• Upload a pre-recorded video in the virtual meeting platform to be available for on-demand viewing throughout the meeting. Our Speaker Management platform is now open for all presenters, and you may record/upload your presentation through the Speaker Management by March 15.

To access Speaker Management and for additional information for presenters and attendees, please visit the ACS Meetings & Expo Presenter Resource page.

Cancellation or Withdrawal
If you are unable to give your presentation, please contact maps@acs.org to withdraw. If you have questions about your presentation or its format, please contact your program chair (see the ACS Spring 2022 Call for Papers for contact information).

Thank you for presenting your research at ACS Spring 2022 and, if you have any questions, please contact us at maps@acs.org.

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Figure 5A. ACS Spring 2022 conference presentation scheduling.

Evaluating the effectiveness of mustard seed meal extract as effective weed control for organic potato farming in the Inland Pacific Northwest

Weed management, soil health, and nutritional quality of organically produced foods are among the highest priority of organic research topics according to organic farmers across the US. Organic farming often relies heavily on tillage to control weeds, but this practice depresses soil health by increasing soil compaction, increasing soil erosion from wind and rain, and disrupting soil microbial communities. Mustard seed meal has proven to be an effective herbicide with potential uses in organic farming but lacks practical application due to needing large quantities to achieve biopesticidal concentrations. By extracting the mustard seed meal into a more concentrated form, however, the extract becomes more logistically viable as an organic herbicide. This study will evaluate the efficacy of mustard seed meal extract in weed control within organic potato farming. Mustard seed meals have also shown to enhance soil health, so this study will also evaluate the effect of the extract on soil health as well as on the nutritional quality of the potatoes produced.

For more information email: Daniel Temmen, dtemmen@uidaho.edu or Inna Popova, ipopva@uidaho.edu.

Photo: Greenhouse trials testing different concentrations of the mustard extract on different weed species in preparation for field trials with potatoes.

Figure 6A. Research highlights published at the University of Idaho website (https://www.uidaho.edu/cals/soil-stewards-farm/research).