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Effect of Seed Meals on Weed Control and Soil Physical Properties in Direct-Seeded Pumpkin

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Received: 2 June 2020; Accepted: 15 July 2020; Published: 19 July 2020

Abstract: Mustard (*Brassica sp.*) seed meal (MSM) and sunflower (*Helianthus annuus* L.) seed meal (SSM) are the byproducts of the seed oil extraction process. They release biologically active allelochemicals that can provide a resource for supplemental nutrients and weed suppression in vegetable cropping systems. Our field experiment aimed to assess the phytotoxic impact of MSM and SSM on weeds and seedling establishment of direct-seeded pumpkin under semi-arid conditions and to study the impact of MSM and SSM on soil physical properties and soil water retention characteristics. The meals were incorporated into the soil 2 weeks before pumpkin planting at two rates (1150 and 2250 kg ha^{-1}). MSM at both rates reduced early season grass and broadleaf weeds by 75 to 82% and 69 to 76%, respectively, as compared to the untreated control. However, SSM at both rates provided 59 to 65% and 54 to 59% controls of narrow and broadleaf weeds, respectively. Both MSM and SSM provided significantly better weed control and pumpkin yield as compared to the untreated control, but higher pumpkin yield was recorded with a lower rate of MSM. In addition, soils amended by both the seed meals had higher saturated hydraulic conductivity, soil water content, and lower bulk density than the untreated control. Overall, our findings suggest that the use of both MSM and SSM as an organic adjuvant is effective in controlling weeds and improving soil physical properties; however, additional research is required to further evaluate these findings and improve the reliability of MSM and SSM for weed suppression following application to agricultural soils.

Keywords: mustard seed meal; sunflower seed meal; narrow leaf weeds; broadleaf weeds; soil water content

1. Introduction

Pumpkin (*Cucurbita pepo* L.) is one of the major specialty crops in the United States and it is produced in almost all the states of the country [1]. Texas ranks fourth in commercial production of pumpkin in the United States [2]. Producers plant 5000 to 8000 acres of pumpkins every year in Texas and 90% of these acres are in West Texas. Pumpkin is primarily grown in a monoculture system in West Texas. One of the major reasons for this monoculture system is the declining water table of the Ogallala Aquifer, which supplements insufficient rainfall for agriculture production in the region. The West Texas region is characterized as semi-arid with an average annual rainfall of 400 mm and high evaporative demand of approximately 2500 mm per year [3]. These weather conditions in the past forced growers to pump significant amounts of water for supplemental irrigation [4,5]. This has resulted in decreased well capacity in most of the areas underlying the Ogallala Aquifer, and eventually prevents growers to take multiple crops in a year. Additionally, the monoculture has allowed growers to be specialized (requiring fewer pieces of equipment) in their farming operations, which helped them to produce a crop at larger volumes [6]. However, these intensive monoculture practices for the past 4–5 decades have increased weed seed bank and deteriorated the environment, especially the soils on which an economically and ecologically viable agriculture depends. Presently, the most prominent risks for sustainable and secure food production are increasing crop pests and declining soil health.

Weeds are one of the most troublesome pests in both conventional [7] and organic [8] vegetable production systems. Weeds interact with crops in various ways. For example, they consume a significant amount of irrigation water planned for crops, and are responsible for water loss through the roots by seepage, and to the atmosphere by transpiration, and thereby contribute to crop water stress [9]. Water use by the crop plants or weeds is related to evapotranspiration, which is a function of the soil, plants, water availability, and climatic conditions [10]. Weeds have a primary negative impact on vegetable yield and quality if remained uncontrolled [11]. On average, weeds can lower crop productivity by 34% [12], lower the value of certain vegetables between 8% to 13% [13] and decrease the quality and market value of vegetables [14]. Furthermore, the damage caused by the weeds mainly depends on environmental conditions and biological properties of the weeds and crop plants [15,16]. The changes in climatic conditions, such as the rapid rise in atmospheric carbon dioxide (CO_2) and the altered temperature and precipitation, have directly helped to increase the arable weeds [17]. Therefore, different weed control strategies need to be explored under different climatic conditions.

From the last half-century, the use of synthetic herbicides has become one of the most dominant methods for weed control due to ease of application, high efficacy, and low cost. Therefore, their widespread use has resulted in soil and groundwater pollution, enhanced accumulation of toxic herbicide residues in agricultural products, increased resistance of weeds to herbicides, and the potential risk to human and animal health [18]. Several studies have shown that synthetic herbicides could cause health problems such as cancer, birth defects, and nerve damage [19]. Additionally, excessive use of herbicides may result in drift contaminating watersheds and other non-target areas [20]. Concerns of ecological, environmental, and health problems associated with the intensive use of synthetic herbicides have encouraged many producers to adopt organic practices and explore other alternatives to control weeds [21,22]. The replacement of synthetic herbicides with natural products would be a sustainable approach to protect the environment and human health. Naturally occurring chemicals found within the plants provide an excellent potential source for producing natural herbicides for weed control in crops [23]. Available natural herbicides for controlling weeds in crops include, among others, a variety of oilseed meals. Unlike chemical herbicides, the use of natural products such as oilseed meals is considered more environment friendly. These oilseed meals are the byproducts of seed oil extraction from oilseed crops such as mustard (*Brassica)*, canola (*Brassica napus* L.), sunflower (*Helianthus annuus* L.), and soybean (*Glycine max* (L.) Merr.). Furthermore, the mustard seed meal (MSM) and sunflower seed meal (SSM) are the byproducts of biodiesel and industrial oil production after oil extraction [24,25]. They release biologically active allelochemicals that can provide a resource for supplemental nutrients and weed suppression in vegetable cropping systems [26–29]. Plants of the Brassicaceae family contain glucosinolates, which are β-thioglucosides with a sulphonated oxime moiety and a variable side-chain derived from amino acids [30]. Glucosinolates are present in all parts of the Brassicaceae plants, but they are most concentrated in the seeds [31]. Upon enzymatic hydration by the addition of water and myrosinase in the seed, glucosinolates produce several allelochemicals as secondary biologically active compounds. These compounds had a negative impact on weed growth and development [32–34].

It has been reported in many studies that MSM can reduce the emergence and growth of both narrow and broadleaf weeds [26,35–37]. Handiseni et al. [38] reported that MSM applied at 2 metric tons (MT) ha^{-1} reduced the emergence and biomass of wild oat (*Avena fatua*), Italian ryegrass (*Lolium multiflorum* L.), redroot pigweed (*Amaranthus retroflexus* L.), and prickly lettuce (*Lactuca serriola* L.). In the same study, they also reported that MSM at 1 MT ha^{-1} was less effective in reducing weed emergence and biomass as compared to 2 MT ha^{-1}. Similarly, Yu and Morishita [37] reported that MSM applied at rates from 2.2 to 6.7 MT ha^{-1} suppressed emergence of annual weeds greater than or equal to corn gluten meal applied at equivalent rates in greenhouse trials. In a 2-year study, MSM applied at 64.4 $g \cdot m^{-2}$ to strawberry reduced weeding time in 1 year but had no effect on weeding time the other year [39]. In a greenhouse study, Earlywine et al. [40] reported >73% control of annual bluegrass (*Poa annua* L.), common chickweed (*Stellaria media* L.), broadleaf plantain (*Plantago major* L.), and white clover (*Trifolium repens* L.) with 168 $g{\cdot}m^{-2}$ of tarped MSM, whereas untarped MSM treatments controlled weeds less consistently. Numerous studies reported the herbicidal effect of MSM on various weeds. However, its effect on direct-seeded vegetable crops under field conditions has not been examined under semi-arid conditions. Similarly, the allelopathic properties of sunflower are well recognized, and their effects on many weeds have been well documented [27,41]. Allelopathic material from sunflowers can influence the antioxidant systems in target plants, causing cell membrane permeability and cellular damage, reducing the target plants' ability to germinate, and causing a gradual loss of seed vigor [42]. However, limited information is available regarding the use of SSM as a potential natural herbicide in organic vegetable production systems, and especially its effect on direct-seeded vegetables.

Similarly, a few studies refer to the effect of seed meals on soil respiration and biochemical properties [43–45]. However, to the best of our knowledge, there is no peer-reviewed article that has yet demonstrated the effects of MSM and SSM application on soil physical properties in vegetable crop production systems. In a few previous studies, the use of other organic materials such as composts and formulated composts from the various urban wastes have had helped to improve the soil physical properties [46], soil chemical properties [47], and the availability of nutrients to crops [48]. Likewise, the use of biochar (i.e., a high carbon coproduct of pyrolysis of organic matter), differing from charcoal by its intention of application as a soil amendment [49], has shown the capacity to decrease soil bulk density, increase nutrient availability, and increase water use efficiency [50,51]. Therefore, it was hypothesized that the addition of MSM and SSM seed meals may improve the soil physical properties to hold soil moisture in addition to weed suppression under the production systems of vegetables such as pumpkin. The main goals of this study were to determine the phytotoxic impact of MSM and SSM on weeds and seedling establishment of direct-seeded pumpkin under semi-arid conditions and to study the impact of MSM and SSM on soil physical properties and soil water retention characteristics.

2. Materials and Methods

2.1. Experimental Description

A field study was conducted during the summer of 2018 at the Texas Tech University Quaker Research Farm in Lubbock, TX (33°33′ N, 101°53′ W, 990 m above sea level) under sub-surface drip irrigation. The predominant soil of the study site consisted of Amarillo sandy clay loam (fine-loamy, mixed, superactive, thermic Aridic Paleustoll) and Olton clay loam (fine, mixed, superactive, thermic Aridic Paleustolls) with 0.8% organic matter and pH of 7.8. The field was fallow two years before the study, and weeds were controlled using both mechanical and chemical methods. The experimental design was a randomized complete block design with five treatments and four replications. The treatments included Pescadero Gold MSM (Farm Fuel Inc., Watsonville, CA) and SSM (C.P.E. Feeds Inc., Brownfield, TX, USA) applied at two different rates. The treatments used were MSM @ 1100 kg ha^{-1} (MM 1) and 2250 kg ha^{-1} (MM 2), SSM @1100 kg ha^{-1} (SM 1) and 2250 kg ha^{-1} (SM 2), and an untreated control. The field was chisel plowed, disked, and harrowed in the spring to prepare the ground for pumpkin planting. Liquid fertilizers were applied through the irrigation system based on soil tests and Texas A&M AgriLife extension recommendations [2]. Both the seed meals were in powdered form and were applied with hands two weeks before the pumpkin planting, and were incorporated into the top 2.5–5.0 cm of soil with the help of a rolling cultivator. Later, pumpkin variety "Howden" (Willhite Seed, Inc., Poolville, TX, USA) was direct-seeded on June 26, 2018, with the help of a drill. The "Howden" variety is a traditional old-time Halloween favorite and is known for its large spreading vines. Rows were spaced 2 m apart, and in-row plant to plant spacing was 0.3 m. The plot size was 9×8 m^2 with 1.5 m alley in-between the plots. Plots were irrigated using a sub-surface drip irrigation system (SDI). The SDI system consisted of drip tapes buried under every row at about 20 to

24 cm deep, with emitters spaced every 61 cm. After planting, irrigation was managed to retain a soil moisture content of at least 50% of the available water capacity for the 0 (soil surface) to 20 cm depth and to provide soil moisture conditions optimum for pumpkin growth [52]. All standard fungicides and insecticides were applied as needed to control pests other than weeds based on Texas A&M AgriLife extension recommendations. No other herbicide was applied to control the weed. Weather data were obtained from the on-site weather station, included daily average air temperature, relative humidity, soil temperature, and rainfall during the crop season in 2018 (Figure 1). The daily average air temperature ranged between 3.4°C and 24.1°C and daily average soil temperature within the 0 to 10 cm depth varied from 19.9°C to 36.6°C. The daily average relative humidity ranged from 32.5% to 98.3%, and the total amount of rainfall during the field experiment was 225 mm.

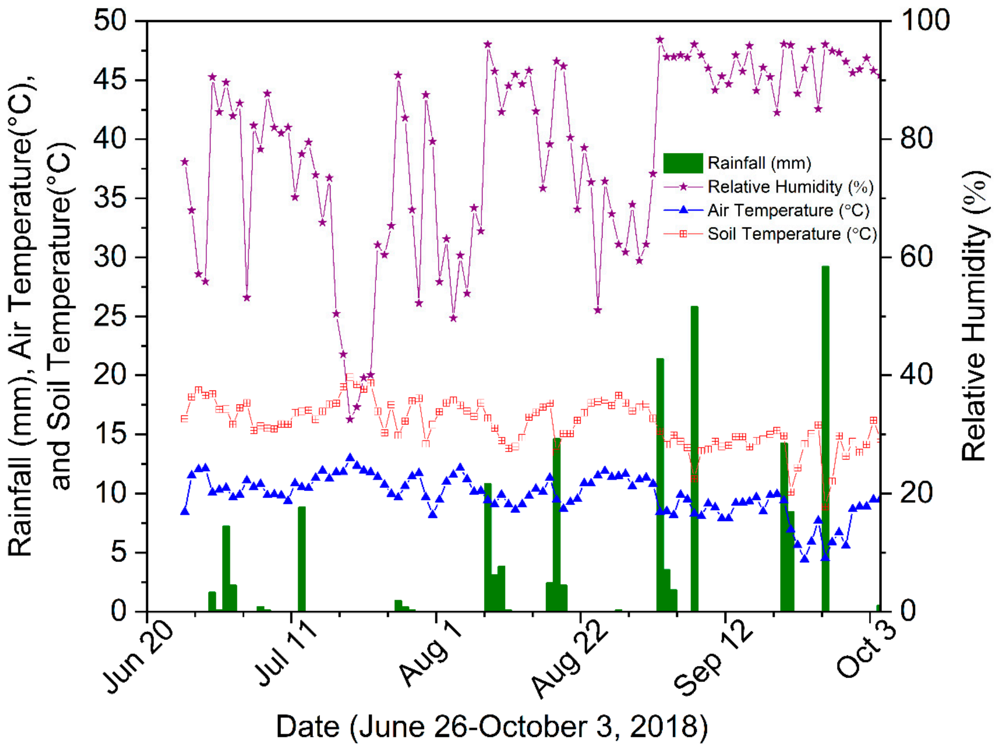

Figure 1. Daily rainfall (mm), relative humidity (%), mean air temperature (°C), and mean soil temperature (°C) at the experimental site at Lubbock, Texas, during the experimental period of 2018.

2.2. Measurements and Data Collection

Visual ratings of weed control and pumpkin injury were recorded based on a scale of 0 (no weed control or pumpkin injury) to 100 (complete weed control or pumpkin death), relative to the untreated check. Weed control ratings and crop injury were recorded 14 days after planting (DAP) and continuing through 25 DAP. Later, weed density by species was recorded on 20 July 2018, and 5 August 2018, by counting all the weeds in a 0.25 m^2 quadrat. The quadrat was randomly placed at four different locations in each plot and all the weeds were counted species wise (narrow and broadleaf). The weed biomass was also sampled by cutting weeds at the soil surface. Weed biomass was then separated into narrow and broadleaf species and dried in an oven at 40 °C for 48 h to determine dry weight.

Additionally, measurements of leaf area index (AccuPAR/LAI Ceptometer Model LP-80) were made on 25 and 40 DAP to detect the toxicity of seed meals on pumpkin plants. A one-time harvest was made on October 10 (75 DAP), 2018. All the pumpkins were harvested from the center rows of each plot, counted, and weighed. Only fruits that were orange, firm, and free from major blemishes or rot were considered marketable, while rotted and unripe fruits were considered unmarketable.

2.3. Soil Sampling and Determination of Soil Properties

The bulk soil samples were collected at 10 cm intervals within the upper 0–50 cm soil depth to determine the soil textures of the experimental field. The bulk soil samples were stored in airtight Ziploc bags, brought to the laboratory, air-dried at room temperature, crushed, and sieved to pass through a 2 mm sieve to conduct particle size analysis using the hydrometer method [53]. The sand, silt, and clay percentages were calculated using the measured hydrometer and suspension temperature data, and the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) soil texture triangle was used to determine the soil texture. Measurements of saturated hydraulic conductivity (Ks) were carried out on collected soil core samples with the Saturated Hydraulic Conductivity (KSAT) benchtop instrument (Meter Group, Inc. Pullman, WA, USA) using both the falling method and the constant method [54]. These soil core (8 cm × 5 cm, i.e., 8 cm diameter and 5 cm height) samples were collected within the top 0–10 cm soil depth from each plot before applying the seed meal treatments to soil and after harvesting of the crop.

The soil water retention curve (SWRC) shows the functional relationship between soil matric potential and water content of the soil. The SWRCs were determined on the 5 cm × 5 cm soil core samples collected at soil depths of 0–5 cm and 5–10 cm by using the pressure plate apparatus (Soil Moisture Equipment Corp., CA). The pressure plate apparatus was used to determine the soil water retention characteristics at 8 different pressures, i.e., 0 (at saturation), −50, −200, −330, −2500, −5000, −10,000, and −15,000 cm H_2O [55]. Soil core samples were saturated from the bottom, and the wetted cores were weighted, and then placed on a saturated ceramic pressure plate in the pressure plate extractor. A predetermined pressure was applied for 24 to 48 h until no more water came out of the cores. Once the soil cores were equilibrated to applied pressure, cores were removed from the extractor and weighed. The same procedure was repeated with successively lower (more negative suction pressure) pressures (from −50 cm to −15000 cm H_2O). The ceramic plates corresponding to higher (saturation to −2500 cm) and lower (−5000 to −15000 cm) saturation were used to determine soil water retention in the wet and dry soil water ranges, respectively. At the end of the experiment, the volumetric and gravimetric water content of soil core samples were calculated from the known bulk density of soil in the cores, the dry weight of soil in the cores, and the weight of soil core at the end of each pressure experiment. The soil bulk density, that is, the ratio of the mass of dry soil solids (after the oven drying soil at 105 °C for 24 h) to the bulk soil volume of the soil (volume of solids with soil pores), was determined using the core method [56]. The plant available water (PAW) was calculated as the difference between field capacity water content (i.e., the upper limit of PAW soil water or the maximum water the soil can hold generally at a suction pressure of −330 cm) and the permanent wilting point water content (i.e., when the plant can no longer extract water from the soil generally at a suction pressure of −15000 cm).

2.4. Statistical Analysis

Data were analyzed using analysis of variance procedures in SAS (Version 9.2, SAS Institute, Cary, NC). The weed density data were prepared for analyses using a square root arcsine transformation to normalize the data. Mean differences were determined using the transformed data and the non-transformed data values are reported using the mean differences determined within the transformed data.

3. Results and Discussion

3.1. Crop Response

The application of MSM and SSM two weeks before planting did not inhibit the pumpkin seedling emergence/germination compared to untreated plots (data not shown). At 15 DAP, no significant crop injury was recorded with SSM at both rates; however, slight injury (7%) was recorded with a higher rate (2250 kg ha^{-1}) of MSM (Table 1). Injury consisted of stunted plant growth and chlorotic leaves. Crop injury was not very extensive and declined 3 to 4 weeks after planting. Further, at 25 DAP, no significant difference in leaf area index was recorded in all treatments (Table 2), indicating that crop injury was recovered later. There is almost no information on the response of pumpkin plants following the pre-emergence application of MSM and SSM, especially at different rates. However, these results were in agreement with previous studies for other crops such as potato plants, where MSM at 2.2 MT ha^{-1} showed a 2% injury on potato plants that were recovered later [26]. In contrast with other studies, MSM at 2.25 and 4.5 MT ha^{-1} severely reduced crop establishment of direct-seeded cucurbits [29], and lettuce emergence was reduced by at least 75% when planted into 3% (w/w) yellow mustard-amended soil earlier than 5 weeks after meal application [23]. Hence, our results indicate that the application of MSM or SSM at or below 2250 kg ha^{-1} two weeks before planting is safe to use in direct-seeded pumpkin.

Table 1. Effect of mustard seed meal (MSM) and sunflower seed meal (SSM) on weed control and crop growth at 15 days after planting (DAP).

Treatments	Rate (Kg ha^{-1})	Visual Weed Control (%)		Crop Toxicity (%)
		Narrow Leaf Weeds	Broadleaf Weeds	
Mustard Seed Meal (MSM)				
MM 1	1150	75.00 ^{b}	68.75 ^{b}	3.75 ^{b}
MM 2	2250	82.50 ^{a}	76.25 ^{a}	7.50 ^{a}
Sunflower Seed Meal (SSM)				
SM 1	1150	58.75 ^{d}	58.75 ^{c}	3.75 ^{b}
SM 2	2250	65.00 ^{c}	53.75 ^{d}	3.75 ^{b}
Untreated control	-	0.00	0.00	0.00

Means within the same column followed by the same letters are not significantly different according to Least significant difference (LSD) at the P = 0.05 level.

Table 2. Effect of mustard seed meal (MSM) and sunflower seed meal (SSM) on early weed control at 25 DAP.

Treatments	Rate (Kg ha^{-1})	Narrow leaf Weed Density (plant m^{-2})	Broadleaf Weed Density (plant m^{-2})	Leaf Area Index
Mustard Seed Meal (MSM)				
MM 1	1150	10.0b ^{c}	7.00 ^{c}	2.26 ^{a}
MM 2	2250	8.00 ^{c}	5.67 ^{c}	2.19 ^{a}
Sunflower Seed Meal (SSM)				
SM 1	1150	10.7b ^{c}	11.3 ^{b}	2.24 ^{a}
SM 2	2250	12.4 ^{b}	7.33 ^{c}	2.15 ^{a}
Untreated control	-	20.3 ^{a}	16.3 ^{a}	2.36 ^{a}

Means within the same column followed by the same letters are not significantly different according to LSD at the P = 0.05 level. Weed density m^{-2} data were square root transformed before mean comparisons. Data presented are the non-transformed mean values.

3.2. Weed Density and Biomass

The most common broadleaf weeds infesting our experimental site were redroot pigweed, common lambsquarters (*Chenopodium album* L.), silver leaf nightshade (*Solanum elaeagnifolium* L.), purslane (*Portulaca oleracea* L.), spotted spurge (*Euphorbia maculate* L.), and Russian thistle (*Salsola tragus* L.). Among the narrow leaf weeds, sandbur (*Cenchrus* L.) and green foxtail (*Setaria viridis* L.) were the most common weeds followed by sedges. At 15 DAP, both the seed meals significantly controlled broadleaf and narrow leaf weeds (Table 1). MSM at both rates reduced early season narrow and broadleaf weeds by 75 to 83% and 69 to 76%, respectively, as compared to the untreated control.

However, SSM at both rates provided 59 to 65% and 54 to 59% control of narrow and broadleaf weeds, respectively. The efficacy of both seed meals decreased with time. Early season total (narrow and broadleaf) weed density was significantly reduced by all seed meal treatments relative to the untreated control (Table 2). However, MM 2 had the lowest narrow leaf (8 plants m^{-2}) and broadleaf (6 plants m^{-2}) weed density. While MM 2 provided 61% and 65% of narrow leaf and broadleaf weed control, respectively, as compared to the untreated control, MM 1 and both SSM treatments controlled weeds less than 60%. Our observations in direct-seeded pumpkin are in essential agreement with previous studies for various crops, where MSM at 2.2 to 4.5 MT ha^{-1} reduced early season weed density in cucurbits, onions, broccoli, and potato [26,29,36,57]. Darby et al. [58] also reported similar results with sunflower and mustard seed meals in sweet corn.

As presented in Table 3, the late season narrow leaf weed density was minimally impacted by MSM or SSM treatments, but narrow leaf weed biomass was significantly reduced from 110.8 g m^{-2} in the untreated control to 48.3 g m^{-2} in MM 2 treatment. Conversely, both broadleaf weed density (2.50 plants m^{-2}) and weed biomass (9.45 g m^{-2}) were significantly reduced by MM 2 treatment relative to the untreated control (92.2 g m^{-2}), and notably, MM 2 provided 90% of broadleaf weed control. Furthermore, SSM at both rates significantly reduced late season weed density and weed biomass compared to the untreated control. Both rates of SSM reduced narrow weed density similar to MM 2 treatment. They had less effect on broadleaf weed density and biomass but, as stated earlier, a significantly better effect than the untreated control (Table 3). Previous studies with Brassicaceae seed meal in vegetable crops have been reported to restrict the weeds in the early season while failing to control later emerging weeds [26,29,36,58]. Our observations, however, yield contrasting results, suggesting that higher rates of MSM provided 90% of broadleaf and 61% narrow leaf weed control, even 40 DAP. This was likely due to the vigorous growing canopy of pumpkin vines that had prevented later emerging weeds from establishing or producing considerable biomass. Moreover, it is worth noting that the pre-emergence application of higher rates of MSM could be properly incorporated into the soil, which likely enhanced and extended the herbicidal effects of MSM on weeds [38].

Table 3. Effect of mustard seed meal (MSM) and sunflower seed meal (SSM) on late season weed control at 40 DAP and on pumpkin yield.

Treatments	Rate (Kg ha^{-1})	Narrow Leaf Weed Density (plant m^{-2})	Broadleaf Weed Density (plant m^{-2})	Narrow Leaf Weed Biomass (g m^{-2})	Broadleaf Weed Biomass (g m^{-2})	Pumpkin Yield (Kg ha^{-1})
Mustard Seed Meal (MSM)						
MM 1	1150	9.50 ^{b}	11.5 ^{b}	46.3 ^{b}	42.9 ^{b}	11093 ^{a}
MM 2	2250	8.50 ^{b}	2.50 ^{c}	48.3 ^{b}	9.45 ^{c}	10849 ^{a}
Sunflower Seed Meal (SSM)						
SM 1	1150	10.0 ^{b}	9.50 ^{b}	53.6 ^{b}	54.9 ^{b}	10496 ^{a}
SM 2	2250	9.00 ^{b}	12.0 ^{b}	50.1 ^{b}	49.9 ^{b}	9980 ^{a}
Untreated control	-	22.0 ^{a}	26.0 ^{a}	110.8 ^{a}	92.2 ^{a}	6858 ^{b}

Means within the same column followed by the same letters are not significantly different according to LSD at the P = 0.05 level. Weed density m^{-2} data were square root transformed before mean comparisons. Data presented are the non-transformed mean values.

3.3. Pumpkin Yield

Both the seed meals provided significantly higher pumpkin yield as compared to the untreated control (Table 3). Compared to the untreated control, the plots treated with MSM and SSM produced 31 to 38% extra pumpkin yield. The highest pumpkin yield (11093 kg ha^{-1}) was recorded with MM 1 treatment. Despite higher early and late season weed control, MM 2 produced less pumpkin yield as compared to MM 1 treatment. The reason could be associated with crop injury at the initial growth stages that contributed to lower pumpkin yield in MM 2 treatment. Our findings were consistent with results from previous studies, which suggest that relatively lower rates of MSM (e.g., 2.2 and

4.5 MT ha^{-1} of MSM) caused minor crop injury but produced higher crop yield [26,29,58]. The lower early season weed control in the SSM treatments and untreated control likely contributed to the lower pumpkin yield in these treatments.

3.4. Soil Physical Properties

The soil texture of the experimental field at 0–50 cm depth was sandy loam. The field was dominated with sand content along with varying amounts of silt and clay content (Table 4). Before the application of seed meal treatments, soil bulk density at 0–10 cm depth ranged from 1.64 to 1.67 g cm^{-3} (Table 5). However, after harvesting the crop, soil bulk density in all the treatments varied from 1.63 to 1.67 g cm^{-3} with the average value of 1.64 g cm^{-3}. Soil bulk density in the untreated control plot was significantly higher than the MSM and SSM treated plots at harvest. Soil bulk density among all the seed meal-treated plots was decreased over time, but no significant difference was observed among all these treatments (Table 5). It is noteworthy that this decrease in soil bulk density during the growing season was not observed in the untreated control plot. The reason for decreased soil bulk density in seed meal-treated plots could be explained by the fact that the addition of seed meals to soils might have acted as an organic material [59]. Generally, it is known that adding organic material to soils is the key to improving soil porosity and thereby reducing soil bulk density [60]. A field study conducted by Celik et al. [61] found that the addition of organic material (i.e., compost and manure) at upper 0–15 cm soil depth decreased soil bulk density. Likewise, our observations suggest that adding MSM and SSM improves soil porosity of sandy loam soils, which have been further explained later in this section (e.g., Figure 2).

Table 4. The particle size distribution and soil texture of various soil depths at the experimental site.

Soil Depths (cm)	Particle Size Distribution (%)			Soil Texture
	Sand	Silt	Clay	
0–10	73.21 ± 0.68 *	10.07 ± 2.21	16.72 ± 0.19	Sandy loam
10–20	61.28 ± 1.19	20.07 ± 1.83	18.65 ± 0.34	Sandy loam
20–30	73.21 ± 2.41	8.14 ± 1.58	18.65 ± 0.43	Sandy loam
30–40	64.99 ± 1.92	16.36 ± 1.34	18.65 ± 0.37	Sandy loam

* Value ± Standard error. Means within the same column followed by the same letters are not significantly different according to LSD at the P = 0.05 level.

Table 5. Effect of mustard seed meal (MSM) and sunflower seed meal (SSM) applications on saturated hydraulic conductivity (Ks) and soil bulk density at 0–10 cm soil depth before planting and after the harvest of pumpkin.

Treatments	Rate (Kg ha^{-1})	Soil Bulk Density (g cm^{-3})		Saturated Hydraulic Conductivity (Ks, cm d $^{-1}$)	
		Before	After	Before	After
Mustard Seed Meal (MSM)					
MM 1	1150	1.66 ± 0.06*	1.64± 0.10 ^{b}	104.4 ± 0.008	107.5 ± 0.0037 ^{a}
MM 2	2250	1.64 ± 0.05	1.63 ± 0.08 ^{b}	105.5 ± 0.0024	108.6 ± 0.0012 ^{a}
Sunflower Seed Meal (SSM)					
SM 1	1150	1.67 ± 0.08	1.64 ± 0.07 ^{b}	106.9 ± 0.0015	107.3 ± 0.0044 ^{a}
SM2	2250	1.65 ± 0.08	1.64 ± 0.11 ^{b}	105.1 ± 0.0026	108.9 ± 0.0032 ^{a}
Untreated control	-	1.66 ± 0.07	1.67 ± 0.09 ^{a}	107.7 ± 0.0019	107.2 ± 0.0029 ^{a}

* Value ± Standard error.Means within the same column followed by the same letters are not significantly different according to LSD at the P = 0.05 level.

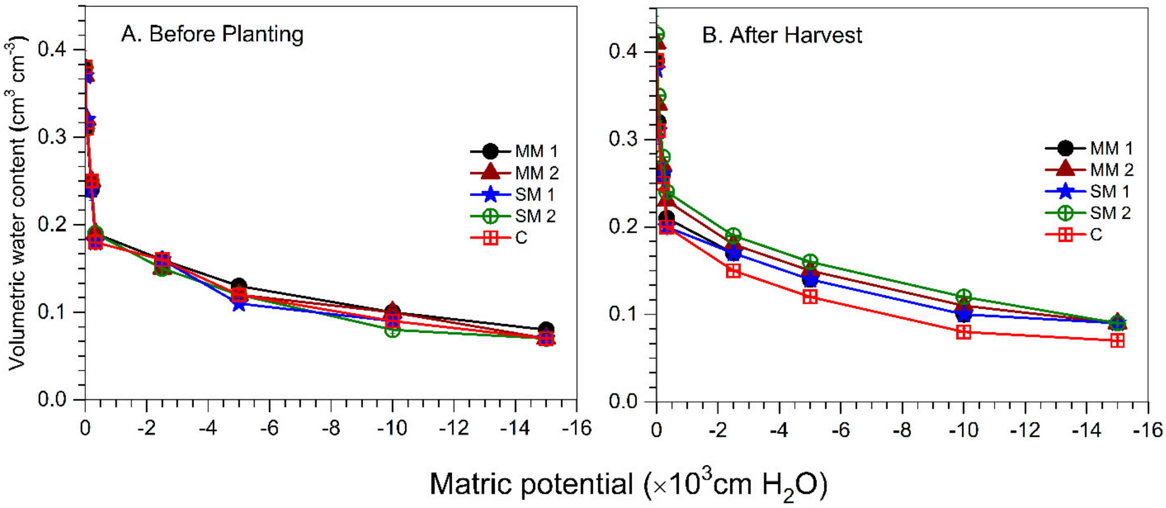

Figure 2. Measured soil water retention curves at 0–10 cm soil depth for different treatments before (**A**) and after harvest (**B**) during 2018. The error bars indicate the standard error of means.

Hydraulic saturated conductivity (Ks) values at 0–10 cm depth were measured before the application of seed meals and after pumpkin harvest (Table 5). Before planting, the average Ks was 105.9 cm d^{-1}, while it was 107.9 cm d^{-1} after harvest. A minor increment in Ks was observed over time in all the MSM and SSM treated plots; however, no significant difference was observed among MSM and SSM treated and untreated plots. Among the SSM treatments at harvest, a relatively higher Ks was observed in SM 2 (higher application rates) compared to SM1, and similarly, among the MSM treatment, MM 2 resulted in a higher Ks as compared to MM 1. Generally, the decreases in soil bulk density, which is dependent on soil textures, are influenced by soil management practices [62], such as seed meal applications in this experiment, which improve soil structure. Therefore, enhanced soil hydraulic properties such as Ks are the most likely results of reduced soil bulk density and increased soil porosity following MSM and SSM applications to soils in the sandy loam pumpkin field.

Soil water retention characteristics (i.e., SWRCs) for the upper 0–10 cm soil depth were measured at different pressures before planting and after the pumpkin harvest (Figure 2). Before the planting, all the samples collected from seed meal-treated and untreated plots showed similar soil water retention characteristics, i.e., similar volumetric water contents corresponding to all applied pressures, were observed between MSM and SSM treatments and the untreated control (Figure 2A). Among all the treatments and untreated control, the values of average volumetric water content measured at saturation (i.e., saturated water content), field capacity, and the permanent wilting point were 0.38, 0.23, and 0.07 cm^{-3}, respectively. However, the SWRCs measured after the pumpkin harvest showed enhanced soil water retention characteristics following different treatments as compared to the untreated control (Figure 2B).

The values for volumetric water content at various pressures especially at saturation (0 cm H_2O), field capacity (−330 cm H_2O), the permanent wilting point (−15,000 cm H_2O) and plant available water (i.e., the difference between field capacity and the permanent wilting point water contents) were obtained from the SWRCs, and changes in soil water retention characteristics among all the seed meal-treated and untreated plots were evaluated and statistically compared (Figure 3).

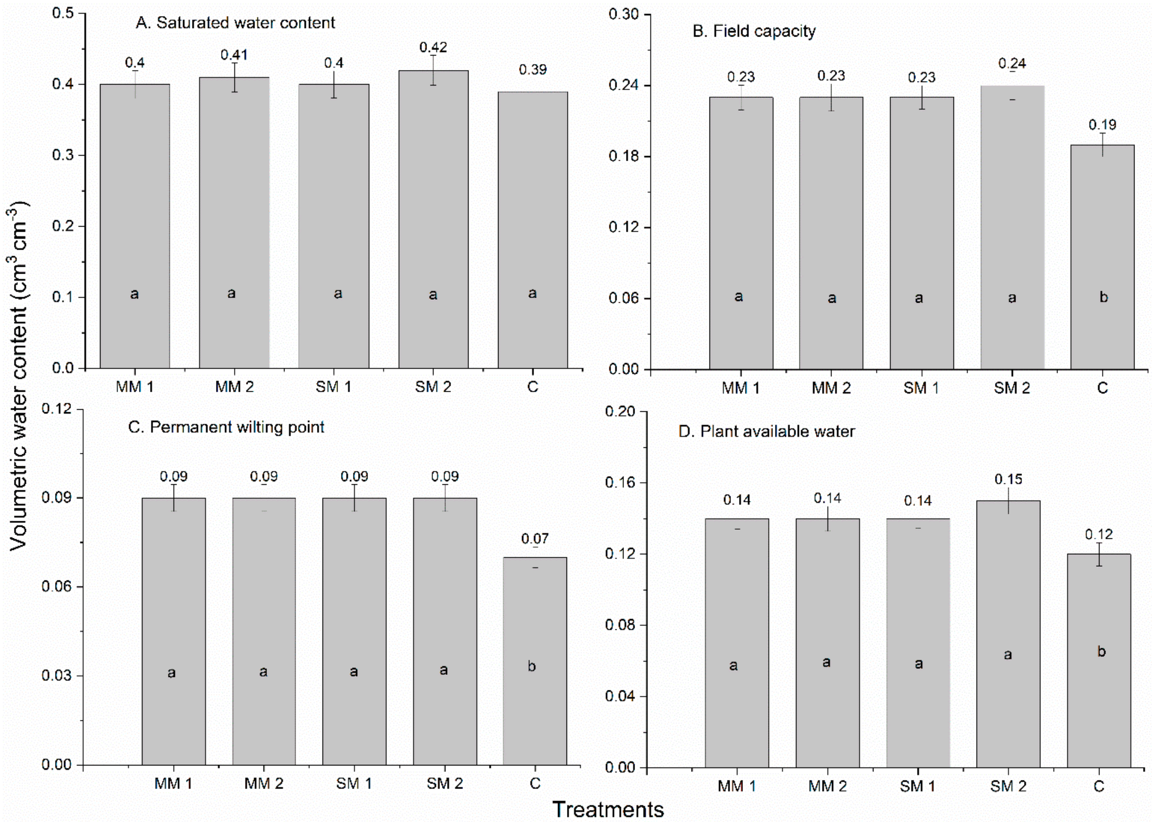

Figure 3. Volumetric water content of soils at 0–10 cm depth (**A**) saturated water content (0 bar pressure), (**B**) at field capacity (−0.33 bar pressure), (**C**) at the permanent wilting point (−0.15 bar pressure), and (**D**) plant available water. Symbols in the *x*-axis (treatments) denote Mustard Seed Meal at 1100 kg ha^{-1} (MM 1) and 2250 kg ha^{-1} (MM 2), Sunflower Seed Meal at 1100 kg ha^{-1} (SM 1) and 2250 kg ha^{-1} (SM 2), and an untreated control (**C**). Means followed by the same letters are not significantly different according to LSD at the P = 0.05 level.

At saturation, the highest volumetric water content, which is generally closely related to or approximately equal to the total soil porosity, was observed in SM 2 (0.41 cm^{-3} cm^{-3}) followed by MM 2, MM 1 and SM 1 treatments, but no significant difference was observed among the treatments. Overall, enhanced saturated water contents following MSM and SSM treatments as compared to the untreated control most likely suggest the improvement in soil structure corresponding to adequate total porosity of the soil. At field capacity where the soil water holding capacity has reached its maximum for all the seed meal-treated plots, the highest volumetric water content was observed in SM 2 treatment, which was not significantly different to the volumetric water contents of MM 2, MM 1 and SM 1. However, all the volumetric water content values from the seed meal-treated plots were significantly higher than the untreated control. Another important aspect to be noted in Figure 2 is that although the volumetric water content at the permanent wilting point was similar, i.e., 0.09 cm^{-3} in all the seed meal treatments, it was significantly higher compared to the untreated control. The plant available water in SM 2 treatment was the highest among the seed meal-treated plots, but it did not differ significantly from the plant available volumetric water contents of MM 2, SM 1, and MM 1.

On the other hand, the plant available water in all the seed meal-treated plots was significantly higher compared to the untreated control. The results showed that the application of seed meals had influenced the soil water retention ability at various pressures. The soil water retention was highly improved after the MSM and SSM treatments both in the wet range of soil water, such as saturated water content and mainly volumetric water content at field capacity, and the dry range of soil water, such as volumetric water content at the permanent wilting point. Several studies showed that soil amendments with both the natural and synthetic products improve the soil water retention capacity and balance the plant available water storage [63,64]. Moreover, incorporation of seed meals into the soil can help to improve the soil nutrient holding capacity, reduce evaporation from the soil, and improve available plant water-released nutrients for the crop growth [65,66]. Of course, improvements in these soil physical properties could be considered a positive response for the vegetable plants such as pumpkins grown in the seed meal-treated sandy loam soils.

4. Conclusions

The results of this study using both MSM and SSM as pre-emergence soil amendments at different rates for controlling weed and improving soil physical properties in direct-seeded pumpkin production suggested that the best overall weed control could be achieved with an application of 2250 kg ha^{-1} of MSM. Both MSM and SSM provided significantly higher early season weed control than the untreated control. However, the effectiveness of both the seed meals decreased with time, except the higher rate of MSM. Direct seeding of pumpkin two weeks after MSM and SSM application did not reduce pumpkin yield. The early season weed control coupled with the shading of late emerging weeds by the crop canopy prevented pumpkin yield loss from excessive weed competition. The addition of seed meals helped to improve the soil water retention mainly at field capacity and the permanent wilting point and, hence, it improves the plant available water content, which is an important aspect for plant growth in sandy loam soils. The results of this study support an alternative use of seed meals as an organic amendment. Overall, a single MSM and SSM application as a pre-emergence soil amendment benefits crop yield, weed suppression, and soil water holding capacity; however, further evaluation of MSM and SSM for weed control following their applications to different agricultural soils is required.

Author Contributions: R.S. conceptualized the study. R.S. and A.S. collected and analyzed the data and prepared the original manuscript. S.K.D. provided technical assistance when the data were analyzed. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors would like to thank Azeez Shaik, Ved Parkash, Manpreet Singh, Bishwoyog Bhattarai, and the farm manager Reagon Anders for their excellent technical support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. United States Department of Agriculture Economic Research Service. Pumpkins: Background and Statistics. Retrieved, 18 October 2019. Available online: http://www.ers.usda.gov/newsroom/trending-topics/pumpkins-background-statistics/ (accessed on 22 June 2020).
2. Smith, D.; Anciso, J. Vegetable Resources: Pumpkins in Texas. Texas A&M AgriLife Extention, Texas A&M University, College Station, TX, USA. 2000. Available online: https://aggie-horticulture.tamu.edu/vegetable/guides/crop-briefs/pumpkins-in-texas/ (accessed on 18 May 2020).
3. Marek, G.W.; Gowda, P.H.; Marek, T.H.; Porter, D.O.; Baumhardt, R.L.; Brauer, D.K. Modeling long-term water use of irrigated cropping rotations in the Texas High Plains using SWAT. *Irrig. Sci.* **2017**, *35*, 111–123. [CrossRef]
4. Singh, S.; Angadi, S.V.; Hilaire, R.S.; Grover, K.; VanLeeuwen, D.M. Spring safflower performance under growth stage based irrigation management practices. *Crop. Sci.* **2016**, *56*, 1878–1889. [CrossRef]
5. Parkash, V.; Singh, S. A review on potential plant-based water stress indicators for vegetable crops. *Sustainability* **2020**, *12*, 3945. [CrossRef]
6. Allen, V.G.; Brown, C.P.; Kellison, R.; Green, P.; Zilverberg, C.J.; Johnson, P.; Zobeck, T.M. Integrating cotton and beef production in the Texas Southern High Plains: I. Water use and measures of productivity. *Agron. J.* **2016**, *104*, 1625–1642. [CrossRef]
7. Pimental, D.; McNair, S.; Janecka, J. Economic and environmental threats of alien plant, animal and microbe invasions. *Agric. Ecosyst. Environ.* **2001**, *84*, 1–20. [CrossRef]

8. McDade, M.C.; Christians, N.E. Corn gluten meal—A natural pre-emergence herbicide: Effect on vegetable seedling survival and weed cover. *Am. J. Altern. Agric.* **2000**, *15*, 189–191. [CrossRef]
9. Zimdahl, R.L. *Fundamentals of Weed Science*, 4th ed.; Academic Press: San Diego, CA, USA, 2013; p. 31.
10. Cano, E.; Musarella, C.M.; Cano-Ortiz, A.; Piñar Fuentes, J.C.; Rodríguez Torres, A.; Del Río González, S.; Spampinato, G. Geobotanical study of the microforests of *Juniperus oxycedrus* subsp. *badia* in the Central and Southern Iberian Peninsula. *Sustainability* **2019**, *11*, 1111. [CrossRef]
11. Fanfarillo, E.; Latini, M.; Iberite, M.; Bonari, G.; Nicolella, G.; Rosati, L.; Salerno, G.; Abbate, G. The segetal flora of winter cereals and allied crops in Italy: Species inventory with chorological, structural and ecological features. *Plant Biosyst.* **2020**. [CrossRef]
12. Oerke, E.C. Crop losses to pests. *J. Agric. Sci.* **2006**, *144*, 31–43. [CrossRef]
13. Pimentel, D.; McLaughlin, L.; Zepp, A.; Lakitan, B.; Kraus, T.; Kleinman, P.; Vancini, F.; Roach, W.J.; Graap, E.; Keeton, W.S.; et al. Environmental and economic impacts of reducing U.S. agricultural pesticide use. In *Handbook of Pest Management in Agriculture*; Pimentel, D., Ed.; CRC Press: Boca Raton, FL, USA, 1991; pp. 679–720.
14. Brown, B.; Hoshide, A.K.; Gallandt, E.R. An economic comparison of weed management systems used in small-scale organic vegetable production. *Org. Agric.* **2019**, *9*, 53–63. [CrossRef]
15. Swanton, C.J.; Weaver, S.; Cowan, P.; Acker, R.V.; Deen, W.; Shreshta, A. Weed thresholds: Theory and applicability. *J. Crop Prod.* **1999**, *2*, 9–29. [CrossRef]
16. Sharma, P.; Singh, A.; Kahlon, C.S.; Brar, A.S.; Grover, K.K.; Dia, M.; Steiner, R.L. The role of cover crops towards sustainable soil health and agriculture—A review paper. *Am. J. Plant Sci.* **2018**, *9*, 1935–1951. [CrossRef]
17. Peters, K.; Breitsameter, L.; Gerowitt, B. Impact of climate change on weeds in agriculture: A review. *Agron. Sustain. Dev.* **2014**, *34*, 707–721. [CrossRef]
18. Jabran, K.; Mahajan, G.; Sardana, V.; Chauhan, B.S. Allelopathy for weed control in agricultural systems. *Crop Prot.* **2015**, *72*, 57–65. [CrossRef]
19. Naik, S.; Prasad, R. Pesticide residue in organic and conventional food-risk analysis. *Chem. Health Saf.* **2006**, *13*, 12–19.
20. Wolf, T. Best management practices for herbicide application technology. *Prairie Soils Crop.* **2009**, *2*, 24–30.
21. Duke, S.O.; Dayan, F.E.; Rimando, A.M.; Schrader, K.K.; Aliotta, G.; Oliva, A.; Romagni, J.G. Chemicals from nature for weed management. *Weed Sci.* **2002**, *50*, 138–151. [CrossRef]
22. Walz, E. *Final Results of the Third Biennial National Organic Farmers' Survey*; Organic Farming Research Foundation (OFRF): Santa Cruz, CA, USA, 1999; Available online: http://www.ofrf:publications/survey/Final.Results.Third.NOF.Survey.pdf (accessed on 22 April 2018).
23. Rice, A.; Johnson-Maynard, J.; Thill, D.; Morra, M. Vegetable crop emergence and weed control following amendment with different *Brassicaceae* seed meals. *Renew. Agric. Food Syst.* **2007**, *22*, 204–212. [CrossRef]
24. Brown, J. *Oil Crop Potential for Biodiesel Production: Summary of Three Years of Spring Mustard Research: Methodologies, Results, and Recommendations*; SR-510-36309; National Renewable Energy Laboratory: Golden, CO, USA, 2006. Available online: http://www.nrel.gov/docs/fy05osti/36309.pdf (accessed on 13 November 2017).
25. Maceiras, R.; Rivero, J.J.; Cancela, M.A.; Urrejola, S.; Sanchez, A. Development and modeling of production of biodiesel from sunflower oil. *Chem. Technol. Fuels Oils* **2010**, *46*, 154–159. [CrossRef]
26. Boydston, R.A.; Vaughn, S.F.; Webber, C.L., III; Chaves-Cordoba, B. Evaluating mustard seed meal for weed suppression in potato (*Solanum tuberosum*). *J. Agric. Sci.* **2018**, *10*, 48–57. [CrossRef]
27. Rawat, L.S.; Maikhuri, R.K.; Bahuguna, Y.M.; Jha, N.K.; Phondani, P.C. Sunflower allelopathy for weed control in agriculture systems. *J. Crop. Sci. Biotechnol.* **2017**, *20*, 45–60. [CrossRef]
28. Varela, R.M. Allelopathic Studies on Cultivars of Sunflower. Master's Thesis, University of Cadiz, Puerto Real, Spain, 1982.
29. Webber, C.L.I.; White, P.M.J.; Boydston, R.A.; Shrefler, J.W. Impact of mustard seed meal applications on direct-seeded cucurbits and weed control. *J. Agric. Sci.* **2017**, *9*, 81–90. [CrossRef]
30. Mithen, R.F. Glucosinolates and their degradation products. In *Advances in Botanical Research*; Academic Press: Cambridge, MA, USA, 2001; pp. 213–262.
31. Borek, V.; Morra, M.J. Ionic thiocyanate (SCN-) production from 4-hydroxybenzyl glucosinolate contained in *Sinapis alba* seed meal. *J. Agric. Food Chem.* **2005**, *53*, 8650–8654. [CrossRef] [PubMed]

32. Gimsing, A.L.; Kirkegaard, J.A.; Bruun Hansen, H.C. Extraction and determination of glucosinolates from soil. *J. Agric. Food Chem.* **2005**, *53*, 9663–9667. [CrossRef]
33. Norsworthy, J.K.; Malik, M.S.; Jha, P.; Oliveira, M.J. Effects of isothiocyanates on purple (*Cyperus rotundus* L.) and yellow nutsedge (*Cyperus esculentus* L.). *Weed Biol. Manag.* **2006**, *6*, 131–138. [CrossRef]
34. Vaughn, S.F.; Palmquist, D.E.; Duval, S.M.; Berhow, M.A. Herbicidal activity of glucosinolate-containing seedmeals. *Weed Sci.* **2006**, *54*, 743–748. [CrossRef]
35. Banuelos, G.S.; Hanson, B.D. Use of selenium-enriched mustard and canola seed meals as potential bioherbicides and green fertilizer in strawberry production. *HortScience* **2010**, *45*, 1567–1572. [CrossRef]
36. Boydston, R.A.; Morra, M.J.; Borek, V.; Clayton, L.; Vaughn, S.F. Onion and weed response to mustard (*Sinapis alba*) seed meal. *Weed Sci.* **2011**, *59*, 546–552. [CrossRef]
37. Yu, J.; Morishita, D.W. Response of seven weed species to corn gluten meal and white mustard (*Sinapis alba*) seed meal rates. *Weed Technol.* **2014**, *28*, 259–265. [CrossRef]
38. Handiseni, M.; Brown, J.; Zemetra, R.; Mazzola, M. Herbicidal activity of Brassicaceae seed meal on wild oat (*Avena fatua*), Italian ryegrass (*Lolium multiflorum*), redroot pigweed (*Amaranthus retroflexus*), and prickly lettuce (*Lactuca serriola*). *Weed Technol.* **2011**, *25*, 127–134. [CrossRef]
39. Miller, T.W. Natural herbicides and amendments for organic weed control. In *Crop Protection Products for Organic Agriculture*; 174175 ACS Symposium Series, 947; Felsot, A.S., Racke, K.D., Eds.; American Chemical Society: Washington, DC, USA, 2006.
40. Earlywine, D.; Teuton, T.; Sorochan, J.C.; Fresenburg, B.; Smeda, R.; Sweets, L. Evaluation of Yellow Mustard Seed Meal for Weed Control ASA, CSSA, and SSSA International Meetings New Orleans 13 February 2008. Available online: http://a-c-s.confex.com/a-c-s/2007am/techprogram/P36683.HTM (accessed on 8 July 2020).
41. Gerald, R.L. Sunflowers (*Helianthus annuus*) are allelopathic to weeds. *Weed Sci.* **1983**, *31*, 37–42.
42. Oracz, K.; Bailly, C.; Gniazdowska, A.; Côme, D.; Corbineau, F.; Bogatek, R. Induction of oxidative stress by sunflower phytotoxins in germinating mustard seeds. *J. Chem. Ecol.* **2007**, *33*, 251–264. [CrossRef] [PubMed]
43. Galvez, A.; Sinicco, T.; Cayuela, M.L.; Mingorance, M.D.; Fornasier, F.; Mondini, C. Short term effects of bioenergy by-products on soil C and N dynamics nutrient availability and biochemical properties. *Agric. Ecosyst. Environ.* **2012**, *160*, 3–14. [CrossRef]
44. Wang, A.S.; Hu, P.; Hollister, E.B.; Rothlisberger, K.L.; Somenahally, A.; Provin, T.L.; Hons, F.M.; Gentry, T.J. Impact of Indian mustard (*Brassica juncea*) and flax (*Linum usitatissimum*) seed meal applications on soil carbon, nitrogen, and microbial dynamics. *Appl. Environ. Soil Sci.* **2012**, *2012*, 1–14. [CrossRef]
45. Zaccardelli, M.; Villecco, D.; Celano, G.; Scotti, R. Soil amendment with seed meals: Short-term effects on soil respiration and biochemical properties. *Appl. Soil Ecol.* **2013**, *72*, 225–231. [CrossRef]
46. Agassi, A.; Hadas, A.; Benyamini, Y.; Levy, G.J.; Kautsky, L.; Avrahamov, L.; Zhevelev, H. Mulching effects of composted MSW on water percolation and compost degradation rate. *Compost Sci. Util.* **1998**, *6*, 34–41. [CrossRef]
47. Zinati, G.M.; Li, Y.C.; Bryan, H.H. Accumulation and distribution of copper, iron, manganese and zinc in calcareous soil amended with compost. *J. Environ. Sci. Health Part B* **2001**, *36*, 229–243. [CrossRef] [PubMed]
48. Zinati, G.M.; Li, Y.C.; Bryan, H.H.; Mylavarapu, R.S.; Codallo, M. Distribution and fractionation of phosphorus, cadmium, nickel, and lead in calcareous soils amended with compost. *J. Environ. Sci. Health Part B* **2004**, *39*, 209–223. [CrossRef]
49. Lehmann, J. A handful of carbon. *Nature* **2007**, *447*, 143. [CrossRef]
50. Glaser, B.; Haumaier, L.; Guggenberger, G.; Zech, W. The 'Terra Preta' phenomenon: A model for sustainable agriculture in the humid tropics. *Naturwissenschaften* **2001**, *88*, 37–41. [CrossRef]
51. Liang, B.; Lehmann, J.; Solomon, D.; Kinyangi, J.; Grossman, J.; O'Neill, B.; Skjemstad, J.; Thies, J.; Luizao, F.; Petersen, J. Black carbon increases cation exchange capacity in soils. *Soil Sci. Soc. Am. J.* **2006**, *70*, 1719–1730. [CrossRef]
52. Orzolek, M.; Elkner, T.; Lamont, W.; Kime, L.; Harper, J. *Agricultural Alternatives: Pumpkin Production*; Penn State Extension, Pennsylvania State University: State College, PA, USA, 2012.
53. Gee, G.W.; Bauder, J.W. Particle-size Analysis. In *Methods of Soil Analysis: Part 1*, 2nd ed.; Klute, A., Ed.; SSSA: Madison, WI, USA, 1986; pp. 383–409.
54. Klute, A.; Dirksen, C. Hydraulic conductivity and diffusivity. Laboratory methods. In *Methods of Soil Analysis—Part 1. Physical and Mineralogical Methods*, 2nd ed.; Klute, A., Ed.; SSSA: Madison, WI, USA, 1986; pp. 687–734.

55. Klute, A. Water Retention: Laboratory Methods. In *Methods of Soil Analysis: Part 1*, 2nd ed.; Klute, A., Ed.; SSSA: Madison, WI, USA, 1986; pp. 635–660.
56. Blake, G.R.; Hartge, K.H. Bulk Density. In *Methods of Soil Analysis: Part 1*, 2nd ed.; Klute, A., Ed.; SSSA: Madison, WI, USA, 1986; pp. 336–375.
57. Shrestha, A.; Rodriguez, A.; Pasakdee, S.; Bañuelos, G. Comparative efficacy of white mustard (*Sinapis alba* L.) and soybean (*Glycine max* L. Merr.) seed meals as bioherbicides in organic broccoli (*Brassica oleracea* Var. *Botrytis*) and spinach (*Spinacea oleracea*) production. *Commun. Soil Sci. Plant* **2015**, *46*, 33–46. [CrossRef]
58. Darby, H.; Hills, K.; Cummings, E.; Madden, R. *Assessing the Value of Oilseed Meals for Soil Fertility and Weed Suppression*; University of Vermont Extension: Burlington, VT, USA, 2010.
59. Fine, K.E.; Cole, J.C.; Penn, C.J. Nitrogen mineralization from canola meal or cottonseed meal with or without soapstock. *HortScience* **2013**, *48*, 891–896. [CrossRef]
60. Tejada, M.; Gonzalez, J.L.; García-Martínez, A.M.; Parrado, J. Application of a green manure and green manure composted with beet vinasse on soil restoration: Effects on soil properties. *Bioresour. Technol.* **2008**, *99*, 4949–4957. [CrossRef] [PubMed]
61. Celik, I.; Gunal, H.; Budak, M.; Akpinar, C. Effects of long-term organic and mineral fertilizers on bulk density and penetration resistance in semi-arid Mediterranean soil conditions. *Geoderma* **2010**, *160*, 236–243. [CrossRef]
62. Zhou, X.; Lin, H.; White, E. Surface soil hydraulic properties in four soil series under different land uses and their temporal changes. *Catena* **2008**, *73*, 180–188. [CrossRef]
63. Xu, S.; Zhang, L.; McLaughlin, N.B.; Mi, J.; Chen, Q.; Liu, J. Effect of synthetic and natural water absorbing soil amendment soil physical properties under potato production in a semi-arid region. *Soil Tillage Res.* **2015**, *148*, 31–39. [CrossRef]
64. Yu, Y.; Peng, R.; Yang, C.; Tang, Y. Eco-friendly and cost-effective superabsorbent sodium polyacrylate composites for environmental remediation. *J. Mater. Sci.* **2015**, *50*, 5799–5808. [CrossRef]
65. Agaba, H.; Baguma Orikiriza, L.J.; Osoto Esegu, J.F.; Obua, J.; Kabasa, J.D.; Hüttermann, A. Effects of hydrogel amendment to different soils on plant available water and survival of trees under drought conditions. *Clean-Soil Air Water* **2010**, *38*, 328–335. [CrossRef]
66. Farrell, C.; Ang, X.Q.; Rayner, J.P. Water-retention additives increase plant available water in green roof substrates. *Ecol. Eng.* **2013**, *52*, 112–118. [CrossRef]