International Journal of
Agriculture, Environment and Food Sciences
JAEFS
e-ISSN : 2618-5946
www.jaefs.com
edit PUBLISHING

Research Article
Int J Agric Environ Food Sci 6 (3): 396-401 (2022)

# Allelopathic effects of sorghum species on weed seed germination and dry matter accumulation in different soil types

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**Citation**
Mango, L., Chitsika, T., Nhete, M. (2022). Allelopathic effects of sorghum species on weed seed germination and dry matter accumulation in different soil types. International Journal of Agriculture, Environment and Food Sciences, 6 (3), 396-401.
**Doi:** https://doi.org/10.31015/jaefs.2022.3.8

**Received:** 20 May 2022
**Accepted:** 08 July 2022
**Published Online:** 01 August 2022

**Year:** 2022
**Volume:** 6
**Issue:** 3 (September)
**Pages:** 396-401

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International Journal of Agriculture, Environment and Food Sciences; Edit Publishing, Diyarbakır, Türkiye.

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## Abstract
Weeds are problematic and burdensome to many smallholder farmers in Zimbabwe. The continued existence of allelochemicals in plants inhibit weed seed germination, plant growth and nutrient uptake. A study was carried out to assess the effects of sorghum species on weed seed germination and dry matter accumulation in different soil types at Duncanstan Farm in Featherstone, Zimbabwe. A 3x3 factorial experiment was laid out in a completely randomized design (CRD) with nine treatment combinations replicated four times. Soil type was the first factor with sand, loam and clay soils. Sorghum plant extracts, *Sorghum arundinacea* and *Sorghum halepense*, formed the second factor, and the control had no extract. All soil types showed significant effects $p<0.05$ in the reduction of germinated weeds treated with *S. arundinacea* and *S. halepense* water extracts compared to the control. There was significant decrease $p<0.05$ in the mean fresh and dry matter accumulation of weed seedlings in both treatments of *S. arundinacea* and *S. halepense* water extracts in all soil types. In sand soil, the mean fresh weights were 33.4g and 36.3g in S. *arundinacea* and *S. halepense* respectively as compared to the control treatment with 58.2g. Similarly, the mean dry weights were 15.4g and 14.9g. In conclusion, *Sorghum arundinacea* and *Sorghum halepense* possess allelopathic effects which can be used for effective weed management. It is recommended that sorghum species be conserved and used as bio-herbicides and in the development of synthetic herbicides.

## Keywords
Allelochemicals, Bio-herbicides, Dry matter, Germination, Water extracts

## Introduction
Smallholder farming systems have great production challenges in terms of effective weed control and management. Most of these farmers struggle or fail totally to control weeds resulting in either total crop failure or reduced yields leading to increased food insecurity worldwide. Weeds compete with crops for growth resources including: light, carbon dioxide, water and nutrients (Farooq et al., 2020). Naeem et al., (2018) revealed that weeds reduce the quality of the crop produce and yields, as well as increase the costs of production and harvesting. Severe weed infestations in crop fields due to abundance of weed seeds in the soil greatly affects crop yields in smallholder farming systems (Kandhro et al., 2015). In Zimbabwe, weeds continue to persist in many agro-ecological regions having a wide and large weed seed bank (Chachar et al., 2009). According to Tesio and Ferrero (2010) weeds have the ability to regenerate and produce many seeds in diverse environmental conditions, provide persistence mechanisms which makes them a temporal and spatial problem. Smallholder farmers mainly fail to cope with this great persistence mechanism even though they try to provide and practice control and management techniques (Scavo & Mauromicale, 2020). Hence it is important for an ecological and biological examination and evaluation of soil weed seed banks so that farmers are capacitated in weed control and management. However, allelochemicals produced naturally by some plants can help greatly in reducing weed seed populations in the soil and the costs associated with weed control (Kandhro et al., 2015). Weeds of the grass

family such as Johnson grass (*Sorghum halepense*), bermunda grass (*Cynodon dactylon*), nut surge (*Cyperus rotundus*) among other several grasses account for great yield losses in cereal crop production. To the sane degree, broad leaved weeds such as pig weed (*Amaranthus spinosa*), black jack (*Bidens pilosa*), false bid weed (*Amaranthus retroflexus*) and others also contribute to the yield losses in broadleaf crops (Bsoul & Hilaire, 2004; Olsen, 2020).

Allelopathic plants produce chemicals from their roots, leachates, crop residues and through volatilization which interferes with plant growth (Dahiya et al., 2017). Consequently, the allelochemicals are capable of reducing water and nutrient uptake by the plant, inhibit photosynthesis, respiration, protein synthesis, cell division, delayed maturation or failure to reproduce as well as inhibition of seminal root thickening (Fageria & Moreira, 2011). According to Hejl & Koster (2004) sorghums produce allelochemicals called sorgoleon which inhibit plant growth by restricting photosynthesis and respiration. Similarly, flavonoids and phenolics suppresses the germination and growth of several plants (Gomaa et al., 2014). When sensitive plants are exposed to compounds with allelopathic properties, the germination and growth of plants is depressed. As such, the allelopathic potential of different parts of the plant may vary from plant to plant, region to region or season to season. A study by Scavo & Mauromicale (2020) revealed that allelopathy has recently been recognized as cheap, eco-friendly and sustainable strategy for effective management of weeds, and it involves mostly farm produce materials. The allelopathic weeds contain compounds with phytotoxic ability in their aerial and underground parts like leaves, flowers, seeds, stems and roots in varying concentrations (Tesio & Ferrero, 2010). In a study by Kandhro et al., (2015) in Pakistan, sorghum and sunflower were found to have high allelopathic potential, containing several allelochemicals such as sorgoleone, glycosides, terpenoids, flavonoids, alkaloids and phenolics. Farooq et al., (2013) also found out that allelopathic compounds secreted by sunflower suppressed the germination and growth by interruption of metabolic activities of wheat plant cells. Other scholars found out that sunflower inhibited seed germination, growth and biomass of *Trianthema portulacastrum* (L.) (Rawat et al., 2012) and *Digera arvensis* (Kaur et al., 2018).

## Materials and Methods

### Description of Study Area

The study was conducted at Duncanstan in Featherstone, 106km east of Harare and 10.5 km off Harare-Masvingo highway (18°43′ 0″ S; 30°49′ 0″ E). It is in agro-ecological region III and receives an average rainfall of 650-750 mm per annum. In summer temperature ranges from 18-32ºC and in winter drops to a range of 7-15ºC. The study site lies at an altitude of 1300m meters above sea level. The area is characterized by red clay loam and sand loamy soils, soil pH ranges from 5.0-6.5. Dominant tree species at the site are Msasa or Zebra wood (*Brachystegia spiciformis*), Golden wattle (*Acacia polycnantha*) and White cutch tree (*Acacia polycantha*) while the dominant grass species are fine thatch grass also known as Tambookie grass (*Hypahrrenia filipendulla*), smooth pig weed (*Amaranthus hybridus*), couch grass (*Cynodon dactylon*).

### Experimental design

A 3x3 factorial experiment was laid out in a completely randomized design with nine treatment combinations replicated four times giving a total of 36 treatment combinations. Soil type (sand, loam and clay) was blocked as the first factor. The second factor was the sorghum plant extract with two types of sorghums, *Sorghum arundinacea* and *Sorghum halepense* and a control without extract. 10litre plastic buckets were used as pots and these were of uniform circumference and height. Pot filling was done prior to soil analysis with 5 kg of respective soils per treatment and moistened with water. Soil samples were taken for analysis to analyze chemical compositions and results are shown in the table below.

Table 1. Soil pH and percentage sand, clay and silt in samples (Kutsaga Research lab results).

| Soil Sample | % Soil Content | | | %Active Soil solids | Soil pH |
|---|---|---|---|---|---|
| | Sand | Clay | Silt | | |
| Sand | 74 | 20 | 6 | 26 | 4.54 |
| Loam | 66 | 18 | 16 | 34 | 6.35 |
| Clay | 48 | 30 | 22 | 52 | 5.61 |

Treatment combinations were randomly assigned to each pot using the random number table. The total number of pots were placed on a flat ground. A control experiment was that of soil type without water plant extract. Treatment combinations were as follows:

Table 2. Experimental treatment combinations

| Water Plant Extract | Soil Type | | |
|---|---|---|---|
| | Sand (S) | Clay (C) | Loam (L) |
| *Sorghum arundinacea* (SA) | $SA_{Sand}$ | $SA_{Clay}$ | $SA_{Loam}$ |
| *Sorghum halepense* (SH) | $SH_{Sand}$ | $SH_{Clay}$ | $SH_{Loam}$ |
| No Extract (NE) | $NE_{Sand}$ | $NE_{Clay}$ | $NE_{Loam}$ |

**Soil and sorghum seed collection**

Soil samples were collected from different areas with respective soil type. Clay soil was collected at Shamva Agricultural College, sand and loam soils were collected at Featherstone. The soil samples were collected using the zig-zag method with a soil auger. Soils were kept under room temperature and pressure. Sorghum seeds were collected at Henderson Weed Research Centre and were sown in plots measuring 10m by 10m where 100 seeds were broadcasted at the onset of the rain season at Duncanstan Farm. Three plots (10m x10m) with *Sorghum arundinacea* and *Sorghum halepense* were monitored for germination and growth of the sorghums under natural environments, no fertilizing and weeding. The sorghums were harvested at six weeks after emergence. Above ground parts, stems and leaves were cut into small pieces and shade dried.

**Plant Extract preparation and application**

The whole plant leaves, roots and stems of sorghum were dried naturally under the shade and weighed until a constant weight has been reached. 5kgs of the dried stems and leaves were soaked in 10 liters to make a concentration of 0.5mols and left soaked for 24hrs. After 24hrs a filter paper or strainer was used to separate the stems and leaves to obtain water plant extract. Each 10 litres plant extract was put evenly in each pot in respect of the assigned treatments. The pots were watered twice a week and weed seed germination and emergence was observed within seven days.

**Data collection and Analysis**

After seven days weed seed emergence was recorded and weed species identified. The total number of weeds emerged per pot was recorded. Weed dry matter accumulation was determined by uprooting all the weeds at four weeks after emergence and oven dried at 70˚C for 72 hours to a constant mass. All the data collected was analyzed using two-way ANOVA with a statistical package GenStat version 14.0. Means were separated using LSD at 5% significant level.

**Results and Discussion**

**Mean number of germinated weeds in sand, loam and clay soils treated with *S. arundinacea* and *S. halepense* water extracts**

The treatments of sorghum water extracts on sand, loam and clay soils showed significant effects $p<0.05$ on the number of germinated weeds for both broad leaved weeds and grasses. There was significant reduction in the mean number of both broad-leaved weeds and grasses in all soil types treated with both *S. arundinacea* and *S. halepense* water extracts compared to the control treatment. The mean number of weeds that germinated for both broad leaved and grasses in all soil types were lower than that in the control treatments. In sand soils there was no significant difference in the mean number of weeds that germinated after treatments of *S. arundinacea* and *S. halepense* for both broad leaved weeds and grasses. For broad leaved weeds the mean number of germinated weeds for both treatments were 53 for *S. arundinacea* and 57 for *S. halepense*. This is also similar to grasses with mean number of germinated weeds of 48 and 44 respectively. There is the same trend of mean number of germinated weeds in all soil types (Figure 1). Clay soils had the highest mean number of weeds that germinated for both broad leaved and grasses with 76:74 for broad leaved and 51:49 for grasses treated with *S. arundinacea* and *S. halepense* respectively.

The mean number of germinated weeds in loam soil decreased with treatment of sorghum water extracts although there was no significant difference between *S. arundinacea* and *S. halepense*. For broad leaves the mean number of germinated weeds were 64:61 and 35:31 for *S. arundinacea* and *S. halepense* respectively (Figure 1). The highest mean number of weeds were recorded in clay soil and there was no significant difference between treatments of *S. arundinacea* and *S. halepense* water extracts. For broad leaves the mean number of weeds were 76:74 and 51:49 for *S. arundinacea* and *S. halepense* treatments respectively (Figure 1). The mean number of weeds that germinated in these soil types were significantly different from their control treatments $p<0.05$.

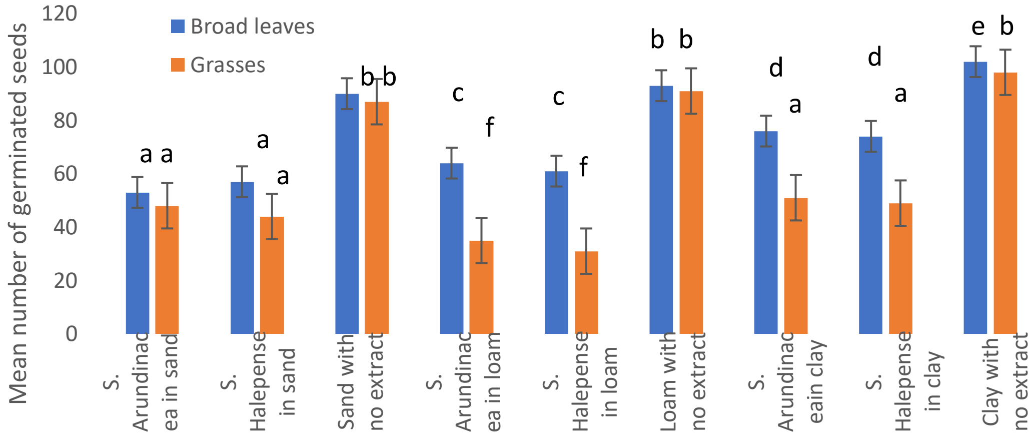


Figure 1. Mean number of germinated weeds in soils treated with sorghum water extracts. Different letters show significant differences ($p<0.05$) for germinated weeds in soils treated with sorghum water extracts

Seed germination is the most crucial growth development stage under water stress conditions for cultivated crops. Many biochemical reactions take place during germination which provides the basic framework for succeeding growth and development of the plant. The data (figure 1) revealed that application of sorghum water extracts from roots and shoots of both sorghum species caused substantial ($p<0.05$) suppression of weeds germination in comparison with the control. Treatments of *Sorghum arundinacea* and *Sorghum halepense* water extracts had allelopathic effects on germination of tested broad leaved and grass weeds. Corresponding results of *Sorghum arundinacea and Sorghum halepense* shoot and root water extracts at 10litre per 5kg soil also conferred statistically significant results similar ($p<0.05$) in the number of germinated broad leaved and grass weeds. There is authenticated suppressive allelopathic effects of *Sorghum arundinacea* and *Sorghum halepense* on germination of both broad leaved and grass weeds. Phytotoxic compounds in water extracts of allelopathic crops were probably solubilized and absorbed rapidly by the germinating seeds in all soil types. The inhibitory effects originate through releasing of allelochemicals from application of water extracts to sand, loam and clay soils (Rice, 2012). When sensitive plants, either crops or weeds, are exposed to compounds with allelopathic properties, the germination of such plants is depressed markedly (Hamidi et al., 2008). In this study, *Sorghum arundinacea* and *Sorghum halepense* water extracts application appeared to be most effective with highest inhibition in germination of weeds as compared to control treatments. Mushtaq et al., (2010) reported that sorghum and sunflower water extract combination at higher concentration (100%) completely inhibited germination of *Trianthema portulacastrum*. In this study, inhibitory effects of *Sorghum arundinacea* and *Sorghum halepense* shoot and roots proved more allelopathic with statistically significant phytotoxic. Allelopathic potential of different parts of plant may vary from each other (Hozayn et al., 2011) and this is in contradictory to the results found in this study. According to Asgharipour (2011) revealed that sunflower leaf extracts had more allelopathic effect on germination of *Digera arvensis* than did on the root extracts and soil incorporation of sunflower residues.

**Weed fresh and dry matter accumulation in g/seedling in sand, loam and clay soil treated with *S. arundinacea* and *S. halepense* water extracts**

There was significant difference $p<0.05$ in the mean fresh and dry matter accumulation of weed seedlings in both treatments of *S. arundinacea* and *S. halepense* water extracts in sand, loam and clay soils. The mean fresh weight and dry weight of the weed seedlings for both broad leaved and grasses decreased in every treatment as compared to the control treatments in all soil types. In sand soil, the mean fresh and dry weights were 33.4g and 36.3g in *S. arundinacea* and *S. halepense* as compared to the control treatment with 58.2g respectively and for dry weight were 15.4g and 14.9g in *S. arundinacea* and *S. halepense* respectively as compared to the control treatment with 23.8g (Table 3). There was also a similar reduction of both fresh and dry weight of weed seedlings of grasses in *S. arundinacea* and *S. halepense* treatments respectively as compared to the control treatments. For grasses the mean fresh weights of 29.8g and 27.6g and dry weights of 13.6g and 12.7g were recorded in *S. arundinacea* and *S. halepense*.

These weights showed a reduction in fresh and dry weights of grasses as compared to the control treatments which had 42.3g and 21.3g fresh and dry weights. This trend was also noted in loam and clay soils treated with *S. arundinacea* and *S. halepense* water extracts. In loam soil the fresh weight and dry weight for broad leaved were 38.7g and 16.1g in *S. arundinacea* treatment and 36.1g and 17.8g in *S. halepense* treatment respectively. There were no significant differences in both fresh and dry weights between the treatments. For grasses the fresh and dry weights were 25.4g and 10.7g in *S. arundinacea* treatment and 24.7g and 11.6g in *S. halepense* treatments. However, there was significant difference in the fresh and dry weights of both treatments compared to the control treatment $p<0.05$. In clay soil the fresh and dry weights of broad-leaved weeds were 41.3g and 21.3g in *S. arundinacea* treatment and 40.4g and 20.7g in *S. halepense* treatment respectively. For the grasses the fresh and dry weights were 33.8g and 14.8g in *S. arundinacea* treatment whilst 35.0g and 15.3g were in *S. halepense* treatment respectively. *S. arundinacea* and *S. halepense* treatments showed significant differences in both fresh and dry weights of all weeds as compared to their control treatments in all soil types (Table 3).

Table 3. Weed fresh and dry matter accumulation in grams/seedling

| Soil/Water extract Treatments | Broad-leaved fresh weight (g) | Broad-leaved dry weight (g) | Grass fresh weight (g) | Grass dry weight (g) |
|---|---|---|---|---|
| Sand with *S. arundinacea* | $33.4^{a}$ | $15.4^{d}$ | $29.8^{a}$ | $13.6^{d}$ |
| Sand with *S. halepense* | $36.3^{a}$ | $14.9^{d}$ | $27.6^{a}$ | $12.7^{d}$ |
| Sand without sorghum extract | $58.2^{b}$ | $23.8^{e}$ | $42.3^{c}$ | $21.3^{e}$ |
| Loam with *S. arundinacea* | $38.7^{a}$ | $16.1^{d}$ | $25.4^{e}$ | $10.7^{d}$ |
| Loam with *S. halepense* | $36.1^{a}$ | $17.8^{d}$ | $24.7^{e}$ | $11.6^{d}$ |
| Loam without sorghum extract | $63.0^{b}$ | $31.0^{a}$ | $44.0^{c}$ | $21.8^{e}$ |
| Clay with *S. arundinacea* | $41.3^{c}$ | $21.3^{e}$ | $33.8^{a}$ | $14.5^{d}$ |
| Clay with *S. halepense* | $40.4^{c}$ | 20.7e | $35.0^{a}$ | $15.3^{d}$ |
| Clay without sorghum extract | $67.2^{b}$ | $32.4^{a}$ | $54.7^{b}$ | $24.6^{e}$ |
| P. value | 0.004 | 0.003 | 0.000 | 0.001 |
| LSD | 0.4 | 0.5 | 0.6 | 0.9 |

Means with the same letter are not statistically different

It is evident from the results obtained (Table 3) that *Sorghum arundinacea* and *Sorghum halepense* water extracts caused marked (p<0.05) inhibition in fresh and dry biomass of both broad leaved and grass weeds. The decrease in fresh and dry biomass of these weeds may be linked to reduced vegetative growth caused by allelopathic compounds present in water extracts of both *Sorghum arundinacea* and *Sorghum halepense*. Allelopathic compounds suppress water and nutrients uptake by roots, reduce photosynthesis and biomass accumulation (Mangao et al., 2020). Sorgoleone (2-hydroxy-5-methoxy-3- [(8 Z,11 Z)-8,11,14-pentadecatriene]-p-hydroquinone), a potent PSII inhibitor produced from sorghum plants is exuded as a reduced inactive form and, after its secretion, is oxidized into an active benzoquinone (Sangeetha & Baskar, 2015). This inhibition in photosynthesis could also contributed to the reduction of fresh and dry weight of weed seedlings. Siyar et al., (2019) reported that phytotoxic compounds present in sunflower decreased chlorophyll contents, root and shoot length, and ultimately biomass of wheat seedlings. Water extracts of *Sorghum arundinacea* and *Sorghum halepense* caused negative allelopathic effects as compared to the control treatments by reducing both fresh and dry weights. Shoots and roots of both *Sorghum arundinacea* and *Sorghum halepense* demonstrated higher inhibitory effects to weed seedlings of both broad leaves and grasses. Similarly, Khaliq et al., (2011) reported that application of sorghum and sunflower water extracts reduced shoot dry weight of horse purslane by 66% over the control. The results of this study are in agreement with Khan et al., (2016) who revealed that allelopathic chemicals in leaf water extracts of sorghum and sunflower significantly suppressed fresh and dry biomass of weeds.

**Conclusion**

Water extracts of *Sorghum arundinacea* and *Sorghum halepense* markedly inhibited germination and growth of weeds over the control experiment. *Sorghum arundinacea* and *Sorghum halepense* shoot and root water extracts caused great allelopathic influence and can be used for effective weed management. The lowest germination, and fresh and dry biomass of both broad leaved and grass weeds were recorded. The sorghum extracts had higher allelochemicals for all weeds that germinated in all soil types. Water extracts proved to be most effective in allelopathic efficacy in sand, loam and less in clay soils.

**Recommendations**

It is recommended that sorghum species be conserved and be used as bio-herbicides in weed control. However, farmers are encouraged to make use of sorghum species in their communities to control weeds both as extracts and in intercrops.

**Compliance with Ethical Standards**

**Conflict of interest**

For this research article, the authors declared that they have no actual, potential or perceived conflict of interest.

**Author contribution**

The contribution of the authors to the present study is equal. Authors have read and approved the final manuscript. The authors have verified that the text, figures and tables are original and that they have not been published before.

**Consent for publication**

The authors of this manuscript have agreed that the paper be published with your journal.

**Ethical approval**

Ethics committee approval is not required.

**Funding**

No financial support was received for this study.

**Data availability**

Not applicable.

**Acknowledgement**

Authors are thankful to Shamva Agricultural College for the provision of clay soil, and Duncanstan Farm in Featherstone for the provision of both loam and sandy soils. We are also thankful to Henderson Weed Research Centre for the provision of sorghum seeds.

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