Phytotoxicity Effects of Two Wood Preservatives: CCA and ACQ. II. The Effects on Seed Germination with Preservative Contaminated Soil

Lehong Jin and Alan F. Preston
CSI/Laporte
5910 Pharr Mill Road
Harrisburg, NC 28075

ABSTRACT

In this paper, the results of a study on the effects of two wood preservatives, chromated copper arsenate (CCA) and ammoniacal copper quat (ACQ) on seed germination using soil contaminated with the preservatives at several levels are reported. Tomato, cucumber and grass seeds were used in the study. The results indicate that CCA contaminated soil imparted some detrimental effects on the seed germination rate as well as on subsequent seedling growth at all concentrations tested with each of the plant species. In contrast ACQ affected these factors only at high concentration levels, while at low levels a growth stimulation effect was observed in some cases.

The results also suggest that the plant species tested in this work have a high level of tolerance to copper. The studies demonstrated that the increase in pH and the presence of ammonia may contribute some positive effects when ACQ is present in the soil at low levels, and that the detrimental effects on seed termination observed using the soil contaminated with CCA appears to be due to the presence of the CCA components, and in particular the arsenic and/or chromium.

INTRODUCTION

As part of our studies into the development and consequences of wood preservative treatments for various applications, we have been investigating the ecotoxicological effects of wood preservatives and treated wood. One facet of this work has involved studies on the potential phytotoxic effects which could arise through the increasing use of treated wood around vegetable and flower gardens.

There has been relatively little published research on the phytotoxicity effects of wood preservatives and/or treated wood. Qvarnstrom has published the most comprehensive studies in this area concluding with a major report being issued (Qvarnstrom, 1982). In this work, several preservatives were studied for their effect on six species and it was found that although all tested preservatives caused some damage to at least one species, the overall phytotoxic effects were small. Topically applied preservatives and pressure treatments with the chromated preservatives CCP and CCA caused little damage. An ammoniacal copper formulation included caused little phytotoxicity except in an enclosed atmosphere where ammonia emissions apparently impacted one plant species. It was apparent from these studies that safe practice dictates either drying, or at least holding, all water-borne treatments for a period after treatment in order to avoid potential phytotoxic effects.

In other previous studies few phytotoxic effects from preservative treated wood on plants have been observed (Linnansalmi, 1958; Wang and Hsieh, 1982). Levi et al (1974) found no assignable uptake of CCA components into grape plants in a field study using CCA-treated southern pine posts. Copper contents of the plants were unaffected by the presence of the treated posts, while the levels of chromium and arsenic found were below the detection limit of the chemical analysis procedure used. In a study of lumber for use in greenhouses, Kaufert and Loerch (1955) found that CCA and copper naphthenate treated wood had the least effect on plant growth in a greenhouse situation while pentachlorophenol, creosote and borate treatments showed negative effects on plant growth in this application. Kundzewicz and Wazny (1990) noted significant species differences in plant susceptibility when exposed to treated wood as well as differences between the three water-borne organic treatments included. Baonza and Franco (1989) in a study on appropriate test methodologies found that the use of vermiculite as a substitute for soil affected both the rate of seed germination and the preservative effects on phytotoxicity.

Speir and coworkers conducted two studies on the effect of preservative contamination in soil (Speir et al, 1992a and 1992b). In the first paper a pot trial to determine the effects, on plant growth and element uptake, of soil amendment with CCA treated, or borate treated sawdust was reported. Three plant types were used and the trial was carried out at both soil pH 5 and pH 7. Amendment with treated sawdust increased soil concentrations of the preservative components. Seeds germinated in all pots, but the borate treatment was generally inhibitory to plant growth. The CCA treatment had no negative effect on any of the plants at either pH. The plant roots concentrated the CCA components to high levels with this effect being more marked at pH 5 than at pH 7. The above-ground parts of the plants had lower concentrations of the preservative components except with boron which concentrated in the above-ground portions of the plants. The second study was carried out with incubation without plants and with soil samples taken for analysis over time. Amendment with treated sawdust increased soil concentrations of the preservative components with each of the treatments. At the levels of soil contamination found there were few negative effects attributable to the CCA or borate amendments on various soil factors affecting plant growth. The negative effects that did occur were generally small and the authors concluded that CCA-treated sawdust may be acceptable as a mulch or garden amendment at the contamination levels observed in their study.

Homan and Militz (1993) studied the possibility of using anti-sapstain treated waste wood as a substrate for growing greenhouse crops and concluded that some types of waste wood may have potential for this application. Their data from both laboratory and larger scale greenhouse tests showed that certain anti-sapstain treatments can have a negative influence on the growth of cucumber plants while with other treatments no such effect was observed. The tests showed that under the conditions used, quat, orthophenylphenol and TCMTB had no apparent influence on either cucumber growth or the cucumbers produced.

In a previous publication (Jin and Preston, 1993), we investigated the potential effects of CCA-treated and ACQ-treated wood on both plant growth and chemical uptake, as well as the effects of these treatment chemicals on seed germination. This study showed little absorption of preservative components into or from soil adjacent to the treated wood, and no effects on plant growth or fruit development. In the seed germination studies included in this work using filter paper as substrate, positive growth effects were observed at low levels, but detrimental effects were apparent at higher levels of the preservatives on germination and subsequent seedling growth. When considering the different effects of seed germination by CCA and ACQ in this study, the issue of whether the observed differences were due to chromium and arsenic from the CCA or possibly to the ammonia in the ACQ acting as a positive nitrogen source for plant growth, was unresolved.

In this current study we have investigated various effects of preservatives in soil on seed germination in greater depth, and have included further chemical treatments and seed species.

MATERIALS AND METHODS

1. Seeds

Three type of seeds, namely tomato, cucumber and grass were chosen for use in this study. The seeds, without any pretreatment coatings such as coated with fertilizers, were purchased from a local horticultural store.

2. Soil

A commonly available potting soil was purchased from a local horticultural store. The moisture content of the soil was predetermined before the soil was treated with the preservative solutions.

3. Soil treatments

The soil was treated with CCA and ACQ solutions to achieve the following chemical retentions (based on total oxides) in the soil: 250, 1250, 2500 and 12500 ug/g. The amount of chemical needed for each targeted retention was calculated based on treating 170g of soil (o.d. weight). The solutions were diluted to a final value of 600g with water. Soil (400g, 57.5% m.c.) was thoroughly mixed with 600g of each treating solution so that a uniform slurry was formed while avoiding the presence of excess free solution. The treated soil was air dried for four weeks to ensure optimal chemical interactions to occur.

In order to verify the chemical treatment levels in the soil, 10g of soil from each treatment was retained for analysis. Soil sample analysis for metals was carried out according to the U.S. Environmental Protection Agency (EPA) Test Methods for Evaluating Solid Waste, Laboratory Manual Volume 1A, Method 3050 (Acid digestion of sediments, sludges, and soil) and the metal contents were determined by the inductively coupled plasma (ICP) spectroscopy method. The methods for extraction of DDAC and the DDAC content determination by HPLC has been described previously (Jin and Archer, 1991).

4. Initial set of seed germination experiments

Treated soils were re-adjusted with water to achieve a final moisture content of 250% before being weighed into a plastic jar in which the seed germination test was carried out. Twenty grams (o.d. weight) of treated soil was weighed into a plastic jar and slightly pressed to form a firm soil layer in the bottom of the jar. Fifteen of the designated seeds were placed on the soil in each assigned jar with each seed being pressed half its length into the soil. The plastic jars were capped. A 20mm hole was made in the middle of the plastic caps and blocked with cotton balls in order to ensure that sufficient air was present in each jar while preventing moisture loss from the soil.

The plastic jars were stored in a temperature controlled room (25-27°C) for 2 weeks during which time the observations on seed germination and subsequent growth of the seedlings were carried out and recorded.

5. Second set of experiments

A second series of experiments was set up after the first experiment had been completed. In these tests only cucumber seeds were used since these seeds germinated very rapidly and uniformly under these conditions. The level of chemical in the soil for these tests was 12500 ug/g.

Two modified soil treatments were included:

1) Copper sulfate and DDAC solution under acidic conditions (CQ)
2) Soil treated with CCA first and then treated with ammonia solution (CCA-M) in order to achieve the same ammonia retention as in the ACQ treatment.

In total this set of experiments included the following four soil conditions: CCA, CCA-M, ACQ, and CQ. The experimental conditions and observations were the same as described in the first set of experiments.

RESULTS AND DISCUSSION

The chemical analysis of the treated soils showed that the chemicals retained in the soil contributed by the treatments were very close to the targeted values. For this reason the nominal retentions have been used in data presented and the discussion of these results.

In the seed germination experiments, germination was completed after a 4 day period for the cucumber seeds and after 8 days for the tomato and grass seeds at all of the contamination levels tested (Tables 1 to 3). Nevertheless, the observations were continued throughout the 14 day experimental exposure period to further examine subsequent seedling growth (Table 4).

The results show that the rates of tomato seed germination in both ACQ and CCA treated soil are slower than with the untreated control soil, though the impact of the soil treatments are different for ACQ and CCA. The example of this effect at the highest concentration (12500 ug/g) is shown in Figure 1. The data for cucumber and grass seeds exhibit the same general trends except in the case of ACQ treated soil with grass seeds at low concentrations where increased and faster seed germination occurred (Figure 2). Retardant effects are clearly observed for CCA treated soil from the lowest concentration tested (250 ug/g), and this growth retardation increases with increasing concentration of CCA in the soil. The example with grass seed germination is shown in Figure 3. It is interesting that the degree of retardation seen in the CCA 250 ug/g treated soil was not observed with ACQ treatment until the concentration of ACQ in the soil reached 2500 ug/g. This result is in agreement with our previous observations (Jin and Preston, 1993) with seed germinations using filter paper as substrate and also confirm the earlier suggestion that seed germination with the species tested is more sensitive to the chemical components in CCA than to the ACQ components.

In our earlier study (Jin and Preston, 1993) we observed that at low addition levels of both ACQ and CCA to the filter substrate, a growth stimulation effect on seed germination with these three species occurred. In contrast, in the present study using a soil substrate, this growth stimulation phenomenon was not significant with either the tomato seeds or with the cucumber seeds, although growth stimulation was apparent in the grass seeds in the presence of ACQ treatments below 2500 ug/g (Figure 4). Comparison of the results of these two studies suggests that the results obtained using either test substrate, soil or filter paper, are qualitatively similar. However, it is apparent that using soil as substrate provides more severe results than is the case with filter paper. Additionally, the results from the soil substrate tests will more closely reflect conditions in practice.

Another significant observation from this study, which has been previously observed (Jin and Preston, 1993) is the retardation and inhibition of seedling growth after the seeds were initially germinated. The results on the seedling heights measured after 14 days are shown in Table 4. It is clear that seedling growth in the soil contaminated with CCA was severely affected at all concentrations studied and with each of the species used in this test (Figures 5 to 7). The presence of ACQ also caused a degree of retardancy on seedling growth. However, in this case the detrimental effect of ACQ at 2500 ug/g was generally equivalent to or less than that observed with CCA at 250 ug/g, the lowest level tested in this study.

The results generated from the second series of experiments are shown in Table 3 and in Figures 8 and 9. From Figure 8, the data demonstrates that when the soil is contaminated with the same amount of ammonia solution in both ACQ and CCA-M treatments, the CCA-M treatment still imparted a significant detrimental effect on the rate of seed germination. On the other hand, when the ammonia was not present in the CQ treatment and the pH of the CQ solution was adjusted to the same as in CCA the seed germination from soil contaminated with CQ displayed some detrimental effect but was much less severe than was apparent in the CCA contaminated soil (Figure 9). When the results from both tests are considered it is not difficult to conclude that although the presence of ammonia and an increase in pH have some positive impact on the overall effects of the systems, the underlining factors which cause the more severe detrimental effect with CCA contaminated soil are the chemical components in CCA. At any given contamination level the copper content contribution from ACQ or CQ is approximately 3.5 times that from an equivalent CCA solution. Nevertheless, the ACQ and CQ contamination have much lower detrimental effects on seed germination than does CCA. This would suggest that the arsenic and/or chromium play significant roles in the effect of CCA on seed germination.

It needs to be noted that the lowest level (nominal) of contamination used in this study was 250 ug/g in soil. The analytical assay (with the background correction) showed that the Cu, Cr and As contents in soil at this treatment level were 39.1, 69.7 and 64.0 ug/g, respectively. These assay values were very close to the target concentration. In the case where treated wood is being used in service, the depletion and accumulation of the chemical components in the soil should be lower than these numbers, and subsequently is unlikely to cause a significant phytotoxic effect on plant growth. However, in applications such as the use of CCA treated sawdust for soil amendment or use as a substrate for crops in greenhouses, caution has to be exercised and further studies in this regard are definitely warranted.

CONCLUSIONS

Measurement of seed germination rates and subsequent seedling growth showed that soil contaminated with CCA exhibited a much more severe detrimental effect on these factors than was seen with ACQ treated soil at the same contamination levels. The detrimental effect in the CCA treated soil was evidenced at the lowest level tested (250 ug/g) with all three plant species. In contrast, soil containing low concentrations of ACQ exhibited stimulation of seed germination and seedling growth in some species. The results also indicate that the plant species tested in this study may have a significant tolerance of copper when present in soil, and conversely the detrimental effects observed with CCA treated soil can probably be ascribed to the presence of the arsenic or/and chromium components. Careful assessment of the risk factors, as well as a further study of the phytotoxicity effects from the residual chemicals, should be carried out prior to the reuse of treated sawdust or waste wood for plant growth applications.

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Table 1. Tomato Seed Germination in CCA and ACQ Contaminated Soils

Treatment		% of Seeds Germinated					
	Level	Test Period (Days)					
	ug/g	1	2	3	6	8	14
Control	0	16.7	63.3	90.0	90.0	90.0	90.0
CCA	250	0.0	33.3	63.3	86.7	86.7	86.7
ACQ	250	0.0	70.0	90.0	93.3	93.3	93.3
CCA	1250	0.0	33.3	46.7	80.0	86.7	86.7
ACQ	1250	0.0	50.0	76.7	86.7	86.7	86.7
CCA	2500	0.0	30.0	53.3	80.0	80.0	80.0
ACQ	2500	0.0	46.7	90.0	93.3	93.3	93.3
CCA	12500	0.0	3.3	26.7	53.3	80.0	80.0
ACQ	12500	0.0	26.7	63.3	90.0	93.3	93.3

Table 2. Grass Seed Germination in CCA and ACQ Contaminated Soils

Treatment		% of Seeds Germinated					
	Level	Test Period (Days)					
	ug/g	1	2	3	6	8	14
Control	0	0.0	10.0	36.7	63.3	70.0	73.3
CCA	250	0.0	0.0	26.7	63.3	66.7	66.7
ACQ	250	0.0	10.0	50.0	76.7	90.0	90.0
CCA	1250	3.3	3.3	3.3	36.7	53.3	60.0
ACQ	1250	6.7	10.0	23.3	63.3	73.3	76.7
CCA	2500	0.0	0.0	0.0	20.0	40.0	46.7
ACQ	2500	0.0	0.0	26.7	53.3	53.3	60.0
CCA	12500	0.0	0.0	0.0	13.3	26.7	26.7
ACQ	12500	0.0	0.0	0.0	16.7	30.0	40.0

Table 3. **Cucumber Seed Germination in CCA and ACQ Contaminated Soils Effect of the presence of ammonia and pH**

Treatment	% of Seeds Germinated				
	Day				
	0	1	2	3	4
Control	0	40.0	100.0	100.0	100.0
ACQ	0	53.3	100.0	100.0	100.0
CQ	0	26.7	73.3	100.0	100.0
CCA	0	3.3	36.7	60.0	96.7
CCA(M)	0	20.0	63.3	83.3	96.7

CQ: Copper sulfate
CCA(M): soil treated with the same amount of ammonia as in ACQ then with CCA.
Contamination level: 12500 ug/g

Table 4. **Seedling Height Measurement After 14 Days Experiment**

Treatment	Level ug/g	% of Controls' Height		
		Cucumber %	Tomato %	Grass %
Control	0	100.0	100.0	100.0
ACQ	250	102.6	102.9	89.3
CCA	250	84.6	79.4	75.0
ACQ	1250	110.3	85.3	82.9
CCA	1250	45.1	44.1	39.3
ACQ	2500	102.6	73.5	82.1
CCA	2500	23.1	23.5	27.1
ACQ	12500	97.4	52.9	28.6
CCA	12500	12.3	20.6	10.0

Figure 1. Tomato Seed Germination in CCA and ACQ Contaminated Soils

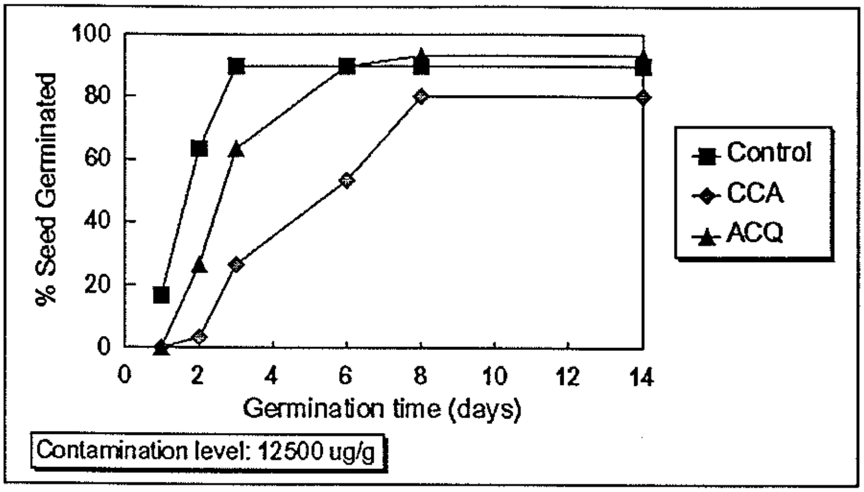

Figure 2. Grass Seed Germination in CCA and ACQ Contaminated Soils

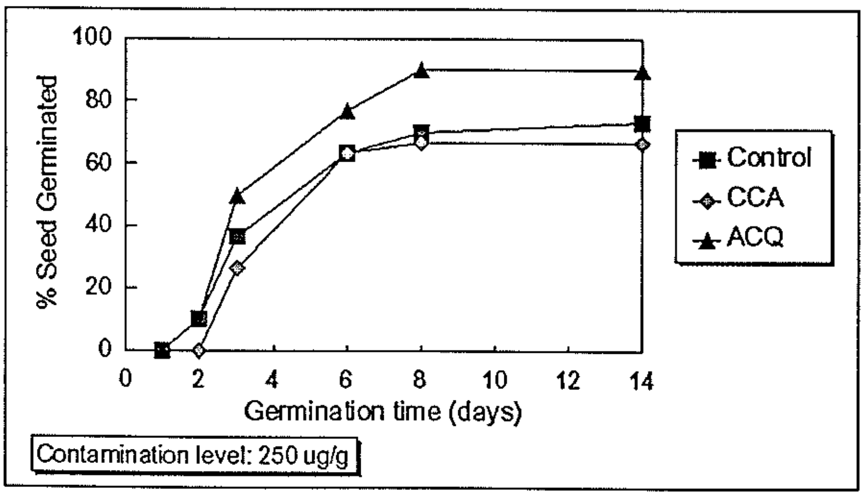

Figure 3. Grass Seed Germination in CCA Contaminated Soils

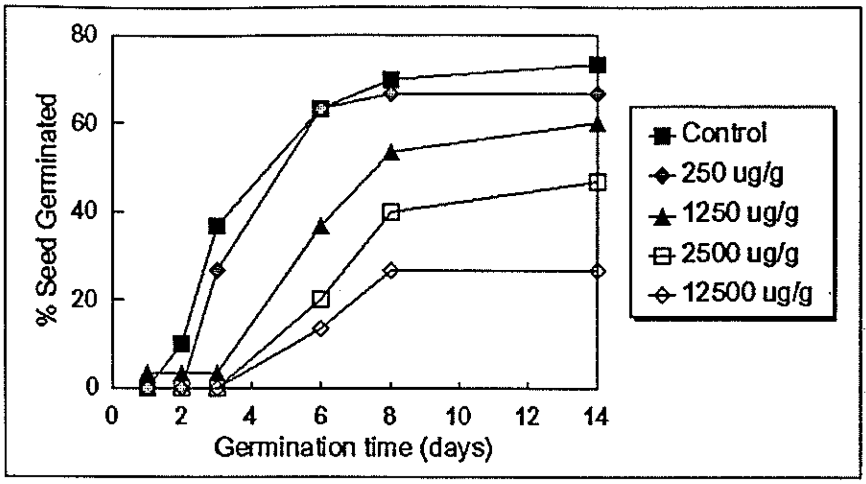

Figure 4. Stimulating Effect on Grass Seed Germination in Soil Contaminated with low levels of ACQ

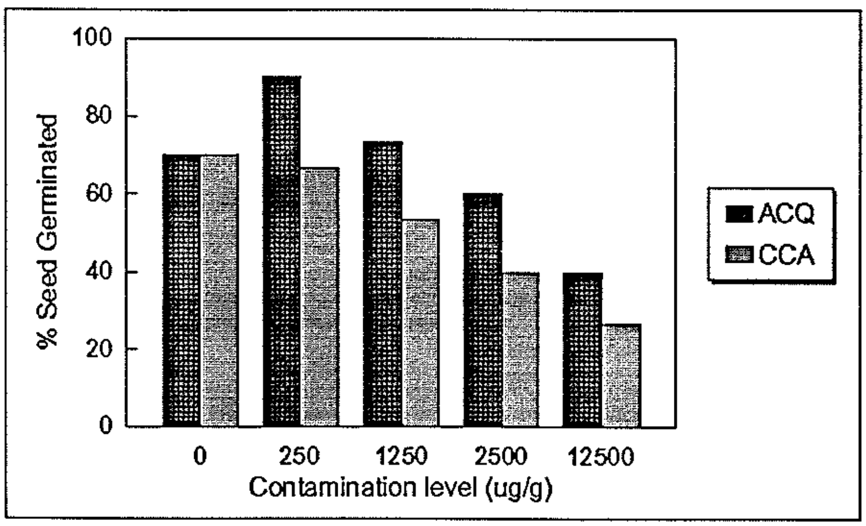

Figure 5. Relative Cucumber Seedling Height to Controls (%)

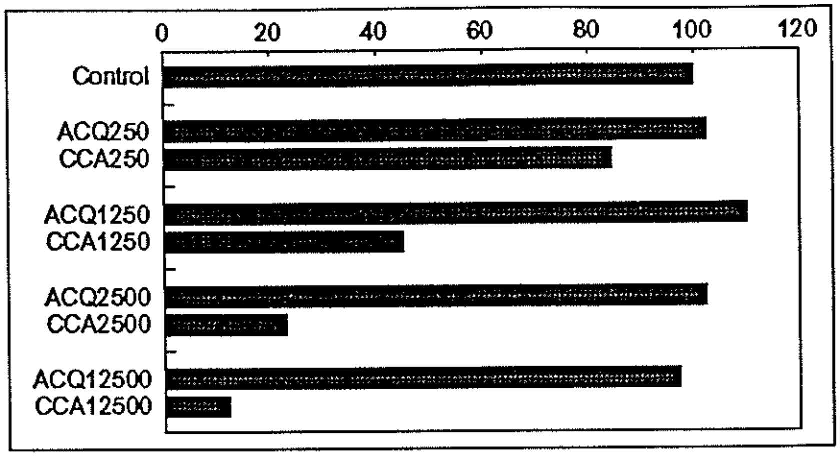

Figure 6. Relative Tomato Seedling Height to Controls (%)

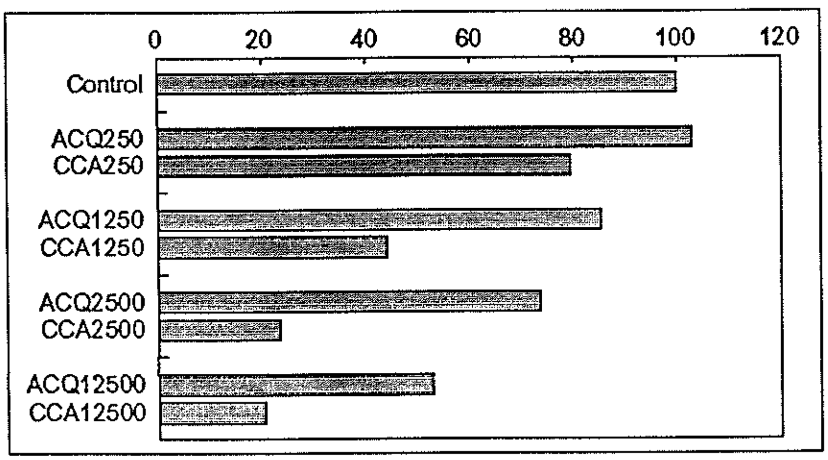

Figure 7. Relative Grass Seedling Height to Controls (%)