THE APPLICATION OF GERMINATION TESTS TO REVEGETATION OF PHOSPHO-GYPSUM TAILINGS: Preliminary Findings[1]

by

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Abstract. Reclamation of phospho-gypsum tailings has become of concern due to the quantities of tailings involved, potentially toxic contaminants of the tailings, and the slow rate of natural revegetation. Preliminary results of germination tests on Alberta tailings are presented. These were used to examine the phytotoxicity of the tailings, the effectiveness of lime and soil amendments, and variation in sensitivity between chosen shortgrass prairie species. Recommendations are then made for future work.

Additional Key Words: Phosphate fertilizer; Reclamation

Introduction

Phospho-gypsum tailings are a by-product of the phosphate fertilizer industry. Phosphate-bearing ore, which has been crushed and beneficiated at the minesite, has been imported to Canada primarily from the Western U.S. and Florida (McBeath 1987).

At the plant site this ore is ground and digested with sulphuric acid to produce phosphoric acid and calcium sulphate (gypsum). The phosphoric acid is then ammoniated to produce ammonium phosphate fertilizer. From 4.5 to 5.2 tonnes of phospho-gypsum tailings are produced for every tonne of phosphoric acid (as P_2O_5) produced (McBeath 1987).

There are approximately 81 million tonnes of phospho-gypsum tailings stockpiled in Canada. About 3.6 million tonnes are being produced annually (Senes 1987), of which 0.8 million tonnes per year are disposed of in watercourses and in the ocean.

In the U.S., over 304 million tonnes of phospho-gypsum tailings are stockpiled, and 30 million tonnes are produced annually (May and Sweeney 1982).

[1]Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada August 27-31, 1989. Publication in this proceedings does not preclude authors from publishing their manuscripts, in whole or in part, in other publication outlets.

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Proceedings America Society of Mining and Reclamation, 1989 pp 363-382
DOI: 10.21000/JASMR89010363
https://doi.org/10.21000/JASMR89010363

Four phosphate processing plants have been shut down in Canada, at an average age of 20 years (Senes 1987). The seven plants presently in operation (or mothballed) range in age from 20 to 58 years. A number of these may also require decommissioning in the near future.

To date, no phospho-gypsum tailings have been reclaimed in Canada, although several planning and research projects are currently underway. The need for environmentally sound procedures for reclaiming these tailings is critical.

A number of researchers are currently examining possible re-use of these tailings, in products such as agricultural amendment, wallboard and aggregate for road construction. The choice of options is limited, in part, by the nature and concentrations of contaminants, particularly radioactive contaminants, in the tailings. Until these difficulties are overcome, phospho-gypsum tailings will be reclaimed in place.

The first consideration in reclamation planning is to select an appropriate end land use. The reclamation plan must balance desirability of end-point land use with the tailings limitations such that an optimal solution considering human health and safety, economics, social needs and environmental concerns is generated.

Revegetation must be feasible for most end land uses, but the rate of natural revegetation of phospho-gypsum tailings is slow.

In our present research we are attempting to determine what hindrances to revegetation exist, and how to overcome them.

This paper will report on the preliminary findings of germination tests used to select suitable species and amendments for phospho-gypsum tailings revegetation. These tests form one part of a larger study on the reclamation of phospho-gypsum tailings in Alberta.

Tailings Characteristics

The physical and chemical properties of phospho-gypsum tailings present special challenges for reclamation. A detailed assessment of specific tailings is currently underway as part of this study Preliminary findings and data from the literature are summarized below.

The primary constituent of the tailings is gypsum (calcium sulphate), comprising roughly 90% by dry weight (May and Sweeney 1983). Another 8% or so is silicates - sand and clay. The rest will be referred to as contaminants.

The contaminants include radioactive species such as uranium, radium, and their decay products, and heavy metals such as aluminum, iron, arsenic, cadmium, chromium, lead and silver (May and Sweeney 1983). Potential concerns include: toxicity to vegetation, bio-accumulation in the food chain, and health effects such as carcinogenicity.

The low pH of fresh tailings, due to the presence of phosphoric and fluorosilicic acids, inhibits revegetation. Deep rooting zone samples (0-3m) from active ponds show pH values of 2.15 to 3.25 (May and Sweeney 1982). However, ponds which remain inactive show a rise in surface pH over time - a pH rise to 5.5 after ten years has been reported in a Texas pond (surface samples - sampling depth not reported) (Naff 1984).

The tailings used for this study, 0-15cm in depth, showed a pH of about 4.5.

Salinity could affect revegetation success. Tailings measurements performed during this study showed conductivity values in the range of 2.24 to 4.47 mmhos/cm. These levels have been found to reduce yields only in sensitive species (Holm 1978).

In addition, the composition of phospho-gypsum does not appear likely to contain all of the essential nutrients in the required balance to sustain plant growth. This is being investigated furthur.

The physical properties of the tailings which appear to be of concern include the influence of hydraulic conductivity and moisture-holding capacity on water availability for plants. This is of particular concern in arid areas, such as the study tailings site.

Properties such as thermal conductivity and surface color may also affect germination success and growth by influencing the temperature at seed depth (Headdon 1980).

In addition, the tailings tend to form a strong surface crust over time. Although this greatly reduces dusting problems, it may act to inhibit root or shoot penetration.

The properties of the tailings must also be considered in planning revegetation operations. For example, the low shear strength of these tailings will require use of wide-track revegetation equipment.

Germination Tests

Germination and early growth tests were used to examine the toxicity of phospho-gypsum tailings, the effectiveness of amendments, and variation in sensitivity between species.

The arid climate of the southern Alberta tailings site limited the species chosen for this study to those appropriate for shortgrass prairie. Species were chosen after consideration of: their autecological properties, such as drought resistance, pH, heavy metal and salinity tolerances, forage quality, and methods of self-propagation; success in other reclamation projects; and, commercial seed availability. The general site conditions were taken from a review of literature and field observations. Laboratory analyses are currently underway to obtain more specific information. Based on the preceding considerations, the species listed in Table 1 were chosen for initial germination testing.

Experimental Method

For each species, four different treatments were tested. These were: filter paper, raw tailings, soil-amended tailings, and lime-amended tailings. The number of treatments was kept to a minimum in order to maximize the number of species tested.

Filter paper was used as a control. The raw or unamended tailings were passed through a 2mm sieve. The third and fourth treatments were tailings mixed with an amendment.

Table 1. Species Chosen for Germination Tests

Ref. No.	Scientific Name (Common Name)
1.	*Agropyron cristatum* (Fairway Crested Wheatgrass)
2.	*Medicago sativa* (Rambler Creeping Alfalfa)
3.	*Kochia scoparia* (Kochia)
4.	*Koeleria cristata* (Junegrass)
5.	*Festuca ovina* (Covar Sheep's Fescue)
6.	*Astragalus cicer* (Monarch Cicer Milkvetch)
7.	*Elymus giganteus* (Russian Wild Rye)
8.	*Agropyron riparium* (Streambank Wheatgrass)

Preliminary chemical characterization indicated that pH may be of most concern for revegetation, being in the range of 4.5. Agricultural grade lime (calcium carbonate) was used as an amendment to neutralize pH. Soil was also chosen, not only for its pH buffering capabilities, but also to provide an improved growth medium and source of essential nutrients. The soil used for this study was taken from the top 15cm of the Ah horizon of an uncultivated area (brown chernozem) adja-cent to and upwind of the tailings.

The two amendments were added to the raw tailings in quantities necessary to raise the pH to 6.5 over a 24 hour period. Tests indicated the following ratios (by weight): 1 part lime to 25 parts raw tailings; 10 parts soil to 25 parts raw tailings. The soil was first passed through a 2mm sieve. The dry amendments and tailings were weighed out and then blended by hand.

The tests were conducted in petri dishes, with about 20 grams of tailings or amended tailings in each dish (apart from the controls). Ten seeds were added to each of 10 dishes, for each combination of species and treatment - 3200 seeds in all. Certified #1 seed was used for *Agropyron cristatum* (#1), *Festuca ovina* (#5) and *Astragalus cicer* (#6). All other seed was Common #1, except *Kochia scoparia*, of unknown grade.

The dishes were placed in indirect sunlight with additional fluorescent light on a laboratory bench. Watering was done with demineralized water on a demand basis. The tests were conducted until the number of seeds still likely to germinate was insignificant.

Approximately 12 observations of each species were performed over the 18 day experiment. The number of seeds in each of the following four categories was recorded; non-germinated seed or dead seedling; germinated, or burst seed coat; radical longer than 1cm (positive geotrophic response); cotyledon free of the seed coat (dicots) or appearance of leaf sheath (monocots); and, appearance of the first true leaf (dicots), or emergence of the leaf from the leaf sheath (monocots).

Preliminary Observations

At the time of writing, the statistical analyses of the germination data are not yet complete. Therefore, only observational data are reported, in point form below. The maximum number of seeds for each combination of species and treatment to reach each of the four data categories is summarized in Table 2.

Table 2. Number of Seeds Reaching Each Growth Stage (n=100)

Stage 1. Germination

	Species*							
Treatment	1	2	3	4	5	6	7	8
control	80	79	33	21	75	30	0	98
raw tailings	87	86	19	14	55	16	0	96
soil/tailings	97	74	20	16	52	16	0	98
lime/tailings	93	78	23	25	54	18	0	95

Stage 2. Radical >1cm

	Species							
Treatment	1	2	3	4	5	6	7	8
control	80	77	23	21	75	27	0	98
raw tailings	87	81	19	14	54	16	0	96
soil/tailings	97	72	17	16	50	14	0	98
lime/tailings	93	76	19	25	54	15	0	95

Stage 3. Cotyledon/Leaf Sheath

	Species							
Treatment	1	2	3	4	5	6	7	8
control	79	67	21	21	75	25	0	97
raw tailings	86	20	4	14	54	16	0	95
soil/tailings	95	17	6	16	50	9	0	95
lime/tailings	92	24	6	24	54	7	0	88

Stage 4. First Leaf

	Species							
Treatment	1	2	3	4	5	6	7	8
control	79	36	0	20	74	1	0	96
raw tailings	81	1	0	13	51	6	0	91
soil/tailings	93	0	0	15	50	0	0	92
lime/tailings	85	1	0	22	22	0	0	80

*Ref. Number	Scientific Name	Common Name
1.	*Agropyron cristatum*	Fairway Crested Wheatgrass
2.	*Medicago sativa*	Rambler Creeping Alfalfa
3.	*Kochia scoparia*	Kochia
4.	*Koeleria cristata*	Junegrass
5.	*Festuca ovina*	Covar Sheep's Fescue
6.	*Astragalus cicer*	Monarch Cicer Milkvetch
7.	*Elymus giganteus*	Russian Wild Rye
8.	*Agropyron riparium*	Streambank wheatgrass

1. There is an inverse relationship between average germination time and germination rate (Figure 1).

2. Although overall growth rates appeared to be consistent within each group of dishes, some variation in germination rates occurred within the same treatment and species. This is likely due to minor differences in watering and light. The experimental design of ten separate dishes for each group of seeds appeared to minimize these sources of error.

3. To determine whether the low germination rates in species #3, 4, 6 and 7 were due to insufficient light, all eight species were germinated under a high-intensity 1000W metal halide lamp. Significant differences occurred in only two species, *Festuca ovina* (#5) and *Astragalus cicer* (#6), where rates were 50% higher.

4. For *Agropyron cristatum* (species #1), germination rates were very high for all treatments. Most germinated seeds reached the first leaf stage, although the loss rate was lower in the control than in the other treatments.

5. *Medicago sativa* (#2) showed high germination rates in all treatments. In the control, only 46% of the germinated seeds reached the first leaf stage, with significant losses in both the radical and cotyledon stages. Negligible numbers of seeds reached the first leaf stage in the raw tailings, and soil and lime amended tailings, with the majority of losses occurring before the cotyledon stage.

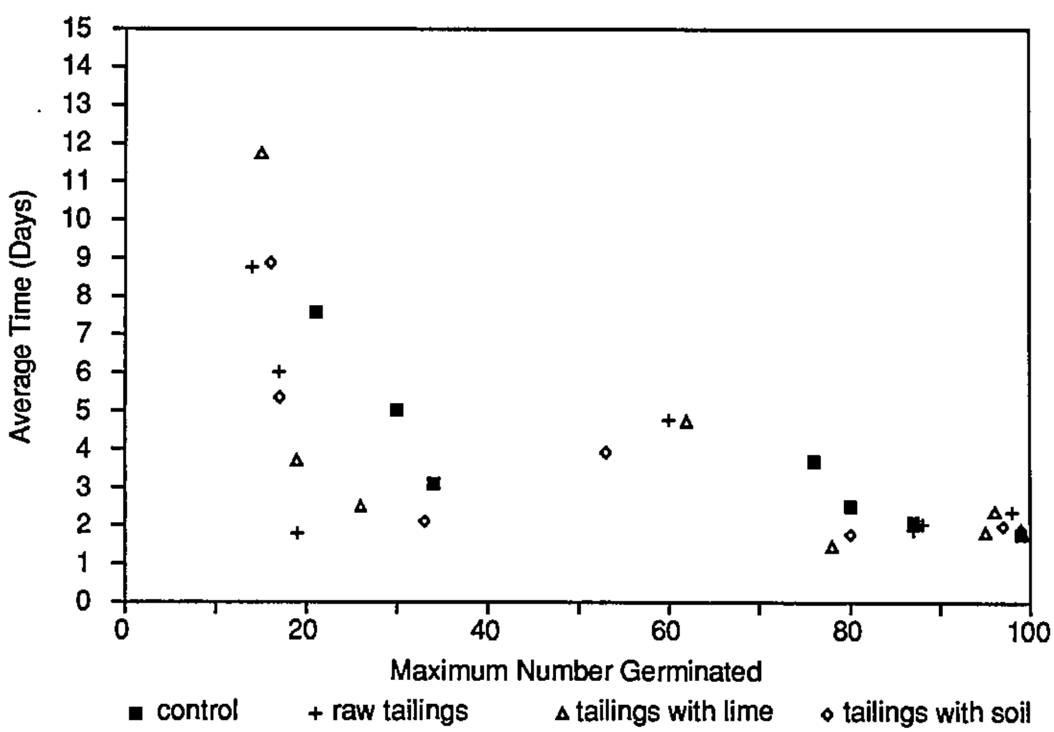

Figure 1. Germination Rate vs Average Time to Germination

6. *Kochia scoparia* (#3) had low germination rates - in the order of 30% for the control, and 20% in the three tailings treatments. None of the seeds reached the first leaf stage. The greatest losses occurred prior to the radical stage for the control, and prior to the cotyledon stage in the other treatments. This species showed the greatest susceptibility to fungi. The Kochia seed used was two years old; this may have negatively affected germination rates.

7. *Koeleria cristata* (#4) had even lower germination rates, ranging from 14% in the raw tailings to 25% in the lime-amended tailings. However, the majority of germinated seeds reached the first leaf stage in all treatments - the greatest loss was 12% in the lime-amended tailings.

8. *Festuca ovina* (#5) had a good germination rate in the control (75%), with slightly lower rates (around 55%) in the other treatments. Like *Koeleria cristata*, the majority of germinated seeds reached the first leaf stage in all treatments, with the greatest loss being 11% in the lime-amended tailings.

9. *Astragalus cicer* (#6) had low germination rates - 30% in the control and 16 to 18% in the other treatments. The number of seedlings reaching first leaf stage was negligible, aside from a small number in the raw tailings. The majority of seedlings in the control and raw tailings reached the cotyledon stage. The losses in the soil and lime-amended tailings occurred evenly before the cotyledon stage and before the first leaf.

10. *Elymus giganteus* (#7) did not germinate at all. The species was relatively unaffected by fungi. The lack of germination is likely due to seed storage conditions or species requirements for some pre-germination treatment.

11. *Agropyron riparium* (#8) had the highest germination rate in all treatments of all the species (97% on average). The majority of germinated seeds reached the first leaf stage, with the greatest losses (16%) occurring in the lime-amended tailings, and the lowest (2%) occurring in the control.

<u>Initial Indications</u>

Agropyron cristatum (#1), *Festuca ovina* (#5) and *Agropyron riparium* (#8) were generally successful to the first leaf stage, regardless of treatment. *Medicago sativa* (#2) showed good germination rates, but was the only species which seemed to show phytotoxicity, i.e. where growth was slower in the raw and amended tailings than in the control. *Elymus giganteus* (#7) did not germinate at all, in any of the treatments.

Kochia scoparia (#3) and *Astragalus cicer* (#6) had low germination rates, and negligible numbers reaching the first leaf stage. *Koeleria cristata* (#4) had a low germination rate, but the majority of germinated seeds reached the first leaf stage.

The chosen growth stages appear to provide an adequate basis for observation of growth. Differences between species and between treatments are apparent. Figure 2 illustrates differences in growth on Day 9 between *Agropyron cristatum*, which appears to show no sensitivity to the tailings, and *Medicago sativa*, which does. The 18 day experimental period appears to be adequate for most species to achieve germination (Figure 3).

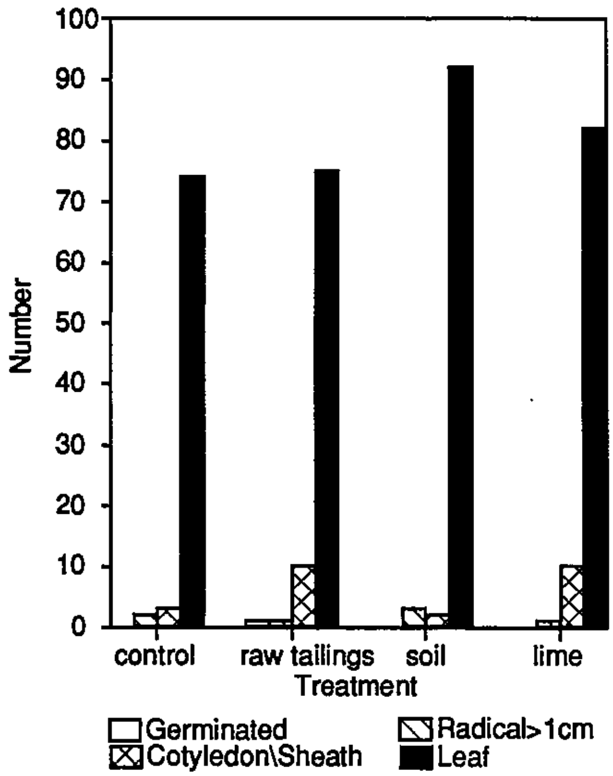

Figure 2a. *Agropyron cristatum:* Day 3

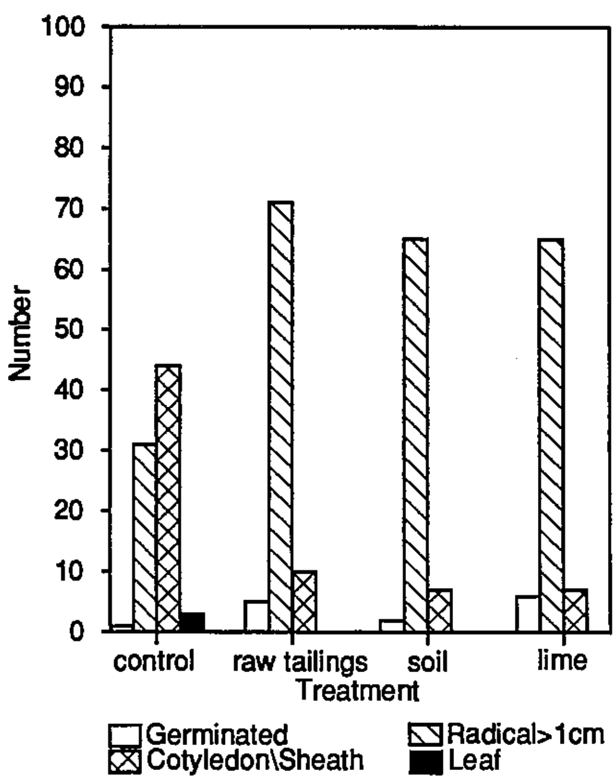

Figure 2b. *Medicago sativa:* Day 3

Seed quality is of primary importance for obtaining meaningful results in a study of this kind. The seed used should be the freshest obtainable, and have been stored under appropriate conditions.

The leaf sheath in monocots seems to appear at the same stage in growth as the cotyledons in dicots, and therefore seems a useful indicator for determining stages of growth.

Fungi are generally associated in this study with high mortality rates prior to germination or at the point of germination, although there is wide variation between species. In case there is a causal relationship between fungi and seed mortality, in future work air circulation will be used and watering kept to a minimum.

Soil appears to be a more effective amendment than lime, yielding higher number of seeds in each growth stage, except for *Koeleria cristata* (#4). Since soil could act to ameliorate phytotoxicity or be supplying nutrients which are deficient in the tailings, this will be examined furthur.

Low germination rates are not necessarily indicative that a particular species is unsuitable for reclamation work. Use of early growth data such as the first leaf stage may provide a better indication than germination alone. The establishment and growth of a species on a reclaimed site is, of course, the final criterion. In the next stages of the study, attention will be given to other means of measurement such as total biomass and seed production.

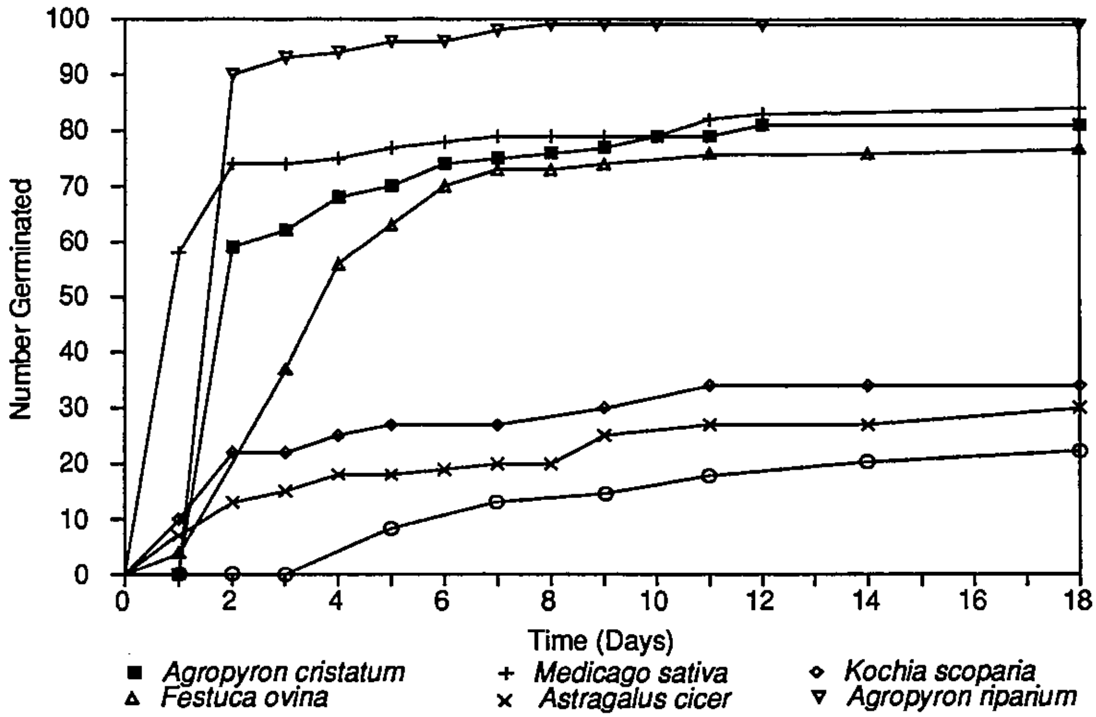

Figure 3. Germination Rate vs Time: Control

Future Work

Due to the low germination rates of half of the species used in this study, and the differences in response between different species to the tailings and amendments, the work will be repeated with several more species. These will be tested first on filter paper to select those with the best germination rates.

Once the germination and early growth test portion of this study is complete, the analytical data involving measurements of nutrient and heavy metal concentrations will be analyzed. These results will be used to select an amendment or set of amendments which allow growth of desirable species on the tailings for a minimum cost.

The next stage in the study will involve longer-term greenhouse tests. These will examine whether the selected amendment added to the raw tailings will provide adequate nutrients to establish vegetative cover, and whether heavy metal uptake varies between species, and what threat it may pose to wildlife.

Acknowledgements

The authors wish to acknowledge Western Co-operative Fertilizers Ltd. for funding this research, and for providing valuable advice. We would also like to thank Prairie Seeds Inc. for providing seed, Stay Sales Ltd. for their co-operation, and Prof. Dennis Parkinson and his staff for laboratory space and guidance.

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