INFLUENCE OF FIRE ON SOIL NUTRIENTS IN A PONDEROSA PINE TYPE[1]

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Abstract. Plant bioassays, with lettuce and ponderosa pine seedlings as indicator plants, and chemical analyses were used to investigate differences in macronutrient availability in soils from areas of different wildfire burn histories. Soils originating from the same parent material were collected from unburned areas consisting of a large control area, having no known history of burning, and two small relict unburned areas, located within two large areas that had been burned over by a severe wildfire at different times in their history. The vegetation, litter, and soil profiles of the relict areas suggested that the soils of these areas were very similar to those of the control area, which indicated that the soils of all three areas were alike before the advent of wildfire into the two burned-over areas. The assays essentially substantiated this conclusion. Soils were collected from the same three areas, with the difference that two were from central locations in the large areas burned over by wildfire. Thus representative soils were obtained from areas with no known history of burning, an old burn (over 12 years old), and a recent burn (3 years old). Assays indicated that nutrient availability in these soils was completely different, and this difference apparently was due to the effect of wildfire on the soils. Fire, through its effect on soil nutrients, could thus exert a profound effect on the nature and growth of the surface vegetation.

INTRODUCTION

The natural regeneration of ponderosa pine in the Southwest is often delayed for many years on large areas burned over by wildland fire (Fig. 1) (Pearson 1950, Gaines and Shaw 1958). Artificial regeneration by means of seeds or seedlings has had only limited success. However, timber-management objectives require that tree seedlings be established, at least on the better growing sites, in these areas. Some of the obstacles to obtaining natural or artificial reestablishment of ponderosa pine seedlings in the Southwest are: (1) impairment of nutrient status and structure of soil brought about by fire; (2) greater extremes of temperature and wind in large open areas; (3) low soil-moisture availability, especially during the spring months of the year due to soil differences and climatic extremes; (4) competition for moisture and nutrients with low brush and forb vegetation occupying the burn sites; or any combination of these factors (Pearson 1950, Gaines and Shaw 1958, Heidemann 1963, Larson 1961, 1967).

The objective of this study was to determine if differences existed in soil chemistry, primarily plant macronutrients, which could be attributed to wildfire histories which differed with respect to time. Soil-nutrient differences in areas burned over by wildfire and in control burned relict areas were evaluated by bioassays, utilizing lettuce plants and ponderosa pine seedlings as indicator plants, and by chemical assays. The nutrients released to the soil by the prescribed burning of surface litter on relict unburned control plots were compared to those present in the areas with different wildfire histories.

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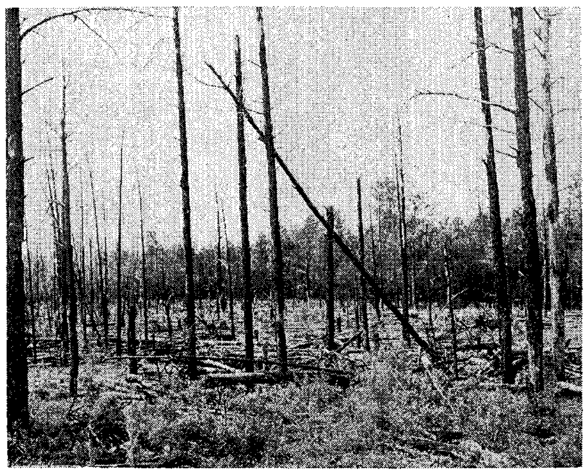

FIG. 1. An area burned over about 10 years ago in the vicinity of the study area having the "old burn" fire history.

LITERATURE REVIEW

The use of fire and its effects on forest nutrition have long been controversial subjects among many workers. Fritz (1931) proposed that fire reduces the productivity of the site. Later work by Wahlenberg (1935), Austin and Baisinger (1955), and Ahlgren (1959) showed some ways in which this productivity was reduced. They were in general agreement that wildfire results in decreased organic matter, decreased soil moisture-holding capacity, and increased concentrations of nutrients in the surface soil layers. The lowered soil moisture-holding capacity was detrimental to seedling survival, while the increased nutrients were beneficial. Most studies on tree nutrition indicate that tree-seedling growth can be increased by adding nutrients to the soil (White and Leaf 1952).

Vlamis, Biswell, and Schultz (1955), using the lettuce bioassay technique of Jenny, Vlamis, and Martin (1950), tested the fertility of several upland soils of California, including many in which ponderosa pine was the dominant plant. The soils tested had a low supplying power for nitrogen and phosphorus. When ponderosa pine seedlings were used as the indicator plants on the same soils, nitrogen was still deficient but phosphorus was only weakly so. Thus ponderosa pine seedlings had a lower phosphorus requirement than lettuce plants.

Vlamis et al. (1959) investigated soil nutrient–fire relationships in two soil types from two ponderosa pine forests in California. Comparing two soils from unburned sites with soils from light and severely burned sites, they found that soils from unburned sites were low in phosphorus and nitrogen and the available phosphorus increased with burn intensity on one soil and not on the other, whereas the available nitrogen increased with burn intensity on all soils. The differences in available phosphorus were explained on the basis of the ability of one soil "to fix phosphate to a high degree." The increased availability of nitrogen was probably due to the phenomenon described by Fowells and Stephenson (1934) who studied nitrification of soil from unburned and burned areas in an incubator. The soils from the burned areas started nitrification sooner and more extensively than the soils from the unburned areas. The same result was achieved in soils from the unburned sites by treatment with calcium.

Description of Study Areas and Plot Selection

Soil samples were collected from three areas in the White Mountains of northern Arizona at elevations between 7,500 and 8,000 ft. One site was on an area burned over 3 years prior to this study (new burn), one on an area burned over 14 years prior to this study (old burn), and one on an area having no recorded or observed history of burning (no-burn history). The soils in all three areas originated from the same parent material. The physical evidence (Fig. 1) indicated that the old-burn and new-burn areas had been subjected to high intensity ground and crown fires. Relict unburned areas located in each of the two burned-over areas (relict) had a vegetational cover that was almost identical in size, density, and species to the no-burn-history area. Litter measurements and visual observations made on the relict and no-burn-history areas of soil profiles exposed in several soil pits indicated that the profiles and litter-humus organic layers were also similar. Level plots typical of the given fire history were subjectively selected for sampling as being most representative of the existing conditions. No attempt was made to sample variation within areas.

The first soil-collection area was located northeast of McNary, Arizona. Two plots were located here; the first was in the new-burn area and the second was in a nearby relict area. The second and third soil-collection areas were located northeast of Pinetop, Arizona. One plot was located in the old-burn area, one was located in a nearby relict area, and one plot was located in the no-burn-history area.

Vegetation

The dominant species on the two relict and the no-burn-history areas was ponderosa pine. Low brush or grasses, or both, and annual forbs occupied the areas on which the ponderosa pine overstory had been destroyed by fire. Wild rose (*Rosa arizonica* (Rudb.)) was the most common brush species, and minute muhly (*Muhlenbergia minutissima* [(Steud.) Swallen]) was the dominant grass. The most abundant forb on the old burn was aster (*Aster commutatus* (Torr. and Gray)), and most abundant in the new burn were wood-sorrel (*Oxalis grayii* (Rose)) and strawberry (*Fragaria bracteata* (Heller)).

Soil description

The soils of the areas in which the three study sites were located were described by S. W. Buol[2] as follows:

> Soils in this area are silt loam in texture developed from pumice material under a multi-aged stand of ponderosa pine at an elevation of approximately 7,500 feet. Pumice particles, ranging from one to three inches in diameter, are distributed throughout the profile and into the clay loam textured lower strata that is apparently the result of a different lithologic deposition or paleosolic horizon. The profiles appeared to be quite uniform in the four pits examined.

Methods of Study

General

Greenhouse bioassays and chemical analyses were made to determine the relative availability of nitrogen, phosphorus, and potassium in soils having three different histories of wildfire. The soils from each plot consisted of a single large random sample collected from each of three soil depths. Each sample from each depth was thoroughly mixed.

Bioassay tests were carried out according to the technique of Jenny et al. (1950). Three lots of 15 pots per soil level per plot were filled with 1,600 g of soil, to provide for three complete bioassays of 135 pots each. Lettuce indicator plants were used for two bioassays and ponderosa pine seedlings of local

[2] S. W. Buol, Asst. Prof., Agr. Chem. and Soils, Asst. Agr. Chemist, Agr. Exp. Sta., Univ. Arizona (from field notes). 1965.

origin were used in one bioassay (Vlamis et al. 1959). Lettuce was used as an indicator plant because its sensitivity to differences in macronutrients had been verified in previous studies (Jenny et al. 1950, Vlamis et al. 1959, Wagle and Vlamis 1961), and the length of time required for bioassay was relatively short. The bioassay results indicated the nutrient deficiencies most likely to influence native ponderosa pine seedling growth and permitted comparison of the sensitivity to nutrients of lettuce and ponderosa pine seedlings.

Each bioassay of soils from each soil depth included: (1) three pots each of a full treatment (NPK) of 160 mg of nitrogen, 240 mg of phosphorus, and 80 mg of potassium; (2) three pots each of three partial treatments—minus phosphorus (NK), minus potassium (NP), and minus nitrogen (PK); and (3) three check pots with no nutrients added. Nitrogen was supplied as ammonium nitrate, phosphorus as monocalcium phosphate, and potassium as potassium sulfate. The 135 pots making up each bioassay study were arranged on a greenhouse bench in a completely randomized block design where the blocks represented the three areas.

At the termination of each bioassay the tops of the indicator plants were harvested, ovendried, and weighed. The results of each bioassay were analyzed statistically to delineate the effects of area, soil depth, and treatment on the dry weight yields. A mean value was calculated for each set of replicates in each bioassay and the means were separated with Duncan's multiple range test.

Differences in yield between treatments for both lettuce and ponderosa pine and chemical analyses of soils from the same soil-profile layers were the basis for the conclusions given. The specific conditions of each study were as follows:

Study I—To determine fertility similarities between soils prior to a history of wildfire.—In the first study, plots located on the two relict areas and on the no-burn-history area were control burned. This technique was used to uniformly minimize the organic constituents of the surface litter so that the nitrogen in the samples of the top layer of soil would not be unduly tied up in the process of decomposing the mixed-in unaltered litter. More uniform mixtures of the soil samples were also possible with larger organic material reduced by fire. The burns were conducted at the same time under the same weather conditions. The burned plots were left untouched until one season of summer rains had leached the ashes. Some nutrient changes probably occurred as a result of these light control burns, but if the organic layers were similar the changes should have been similar and controlled burning seemed to offer the best solution to reducing the larger particles of litter for inclusion in the soil samples. Light burning appeared to be a better alternative than removing the litter prior to sampling. The soils were then collected and bioassayed; lettuce was used as the bioassay plants. No variation in the bioassay results would indicate that the soils in the three areas were similar prior to their wildfire histories.

Study II—To determine fertility differences between soils after different histories of wildfire.—If Study I indicated similarities in soils from the control-burned relict and no-burn-history areas, then the assumption could be made that differences in fertility between the soils from the areas burned over by wildfire would be functions of either fire intensity or fire and time. Soils from the three plots having the different burn histories were bioassayed with lettuce indicator plants.

Study III—To show effect of differences in soil fertility on tree growth.—The soils used in the preceding study were bioassayed with ponderosa pine seedlings as the indicator plants.

Study IV—Chemical analyses.—Soils used in studies I through III were chemically analyzed for NO_3 and CO_2-extracted phosphate to determine N and P content. The soil nutrients were extracted by bubbling a carbon dioxide mixture through a soil-water mixture, and quantitative analyses were made with a photoelectric colorimeter (Jackson 1958).

Results

The results given are directly applicable only to the plots from which the soil samples were collected. Because large soil samples were needed for these tests, physical limitations made it impossible to sample variations within areas, although variations within and between soil samples were tested. However, the differences visually observed between areas having different burn histories in vegetation, environment, and surface litter were so extreme that soil chemistry should have been different between soils from the new-burn, old-burn, and no-burn-history areas.

The no-burn-history area and the two relict unburned areas located within the new and old burns showed striking similarities in vegetation, environments, and soil profiles; thus, similarities in soil chemistry were to be expected. Conclusions, based on inferences made from both visual observations and experimental results, were then made on the influence of fire on the availability of soil nutrients of nitrogen, phosphorus, and potassium.

Similarities in soils from relict areas and the no-burn-history area

Lettuce yield responses (Fig. 2) indicate that the nutrient characteristics of the soils from the no-burn-history area and two relict areas were similar. Because these relict areas were covered with vegetation identical in form and structure to the vegetation found on the no-burn-history area and because these relict areas were located in two areas burned over by wildfire and because the soil parent materials, depth, and physical characteristics were similar in all three areas, it was concluded that the soils from the burns surrounding the relict areas must have been similar to those of the no-burn-history area prior to their invasion by wildfire. This conclusion is borne out by an analysis of the mean yields which were compared by Duncan's multiple range test. Treatments not underscored by the same line within soil layers (Fig. 2) were significantly different in their growth responses. Treatments between soil layers not underscored by the same line also resulted in significantly different growth responses. Differences between soils from the collection areas were also

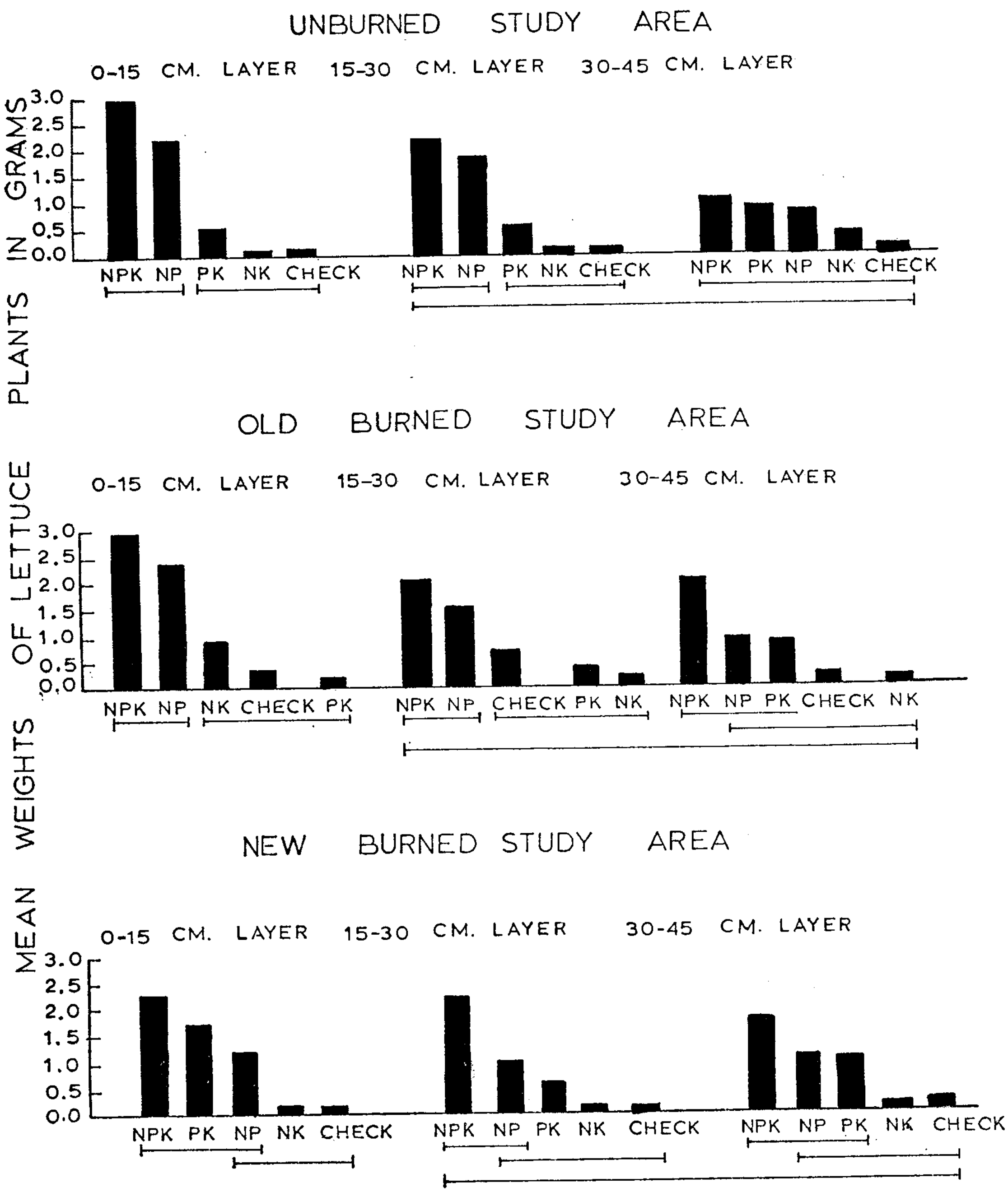

FIG. 2. Lettuce yields obtained from soils collected from three control-burned areas, one from each of two relict unburned areas surrounded by areas burned by wildfire, and one from a large area having no known history of burning.

analyzed statistically, and the similarities in soil fertility from the three areas are shown in Fig. 2.

The chemical analyses made for nitrogen and phosphorus on soils collected from the three control-burned areas also support the conclusion that these soils were similar before their history of wildfire (Table 1). The nitrogen and phosphorus contents of each of these soils were very similar except that the phosphorus level was exceptionally high in the 15- to 30-cm layer in the old-burn relict area.

Differences between soils from plots with different burning histories

Lettuce bioassays on the three soils with different histories of wildfire showed that the soils differed in nitrogen, phosphorus, and potassium availability (Fig. 3). Comparisons made by treatments, layers, and soil-collection areas resulted in the following conclusions:

1) The fire history, which involved intense heat

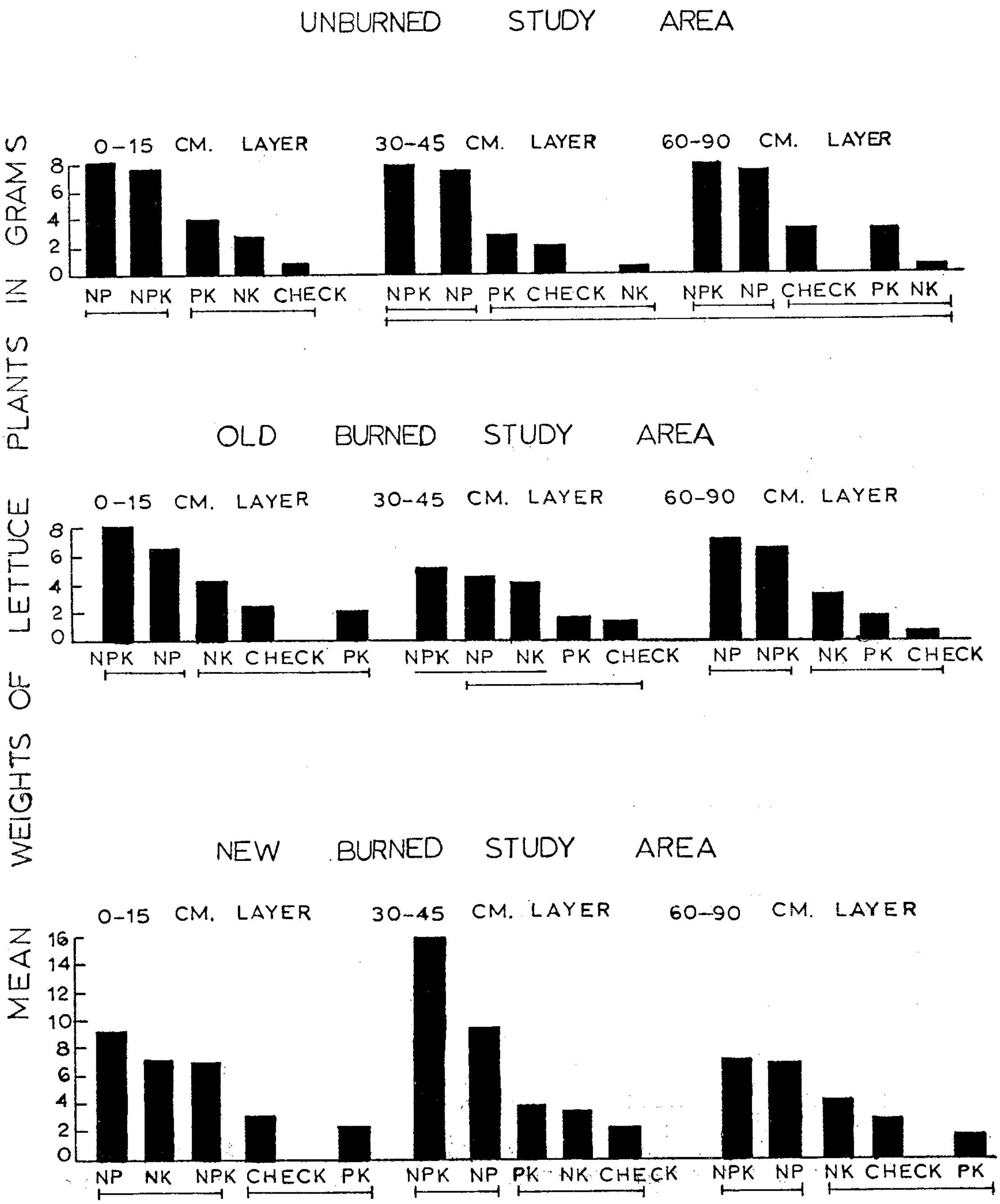

FIG. 3. Lettuce yields on soils collected from areas with three different histories of wildfire.

and complete destruction of the surface litter, caused profound differences in nitrogen and phosphorus levels between these soil profiles. Soils from both the no-burn-history and old-burn study areas showed similarities in the 0–15-cm soil layers with the greatest differences existing between soils collected from the 30–45-cm profile level.

2) Differences in nutrient levels occurred between the soil profiles of the plots with different wildfire histories which did not occur between the soil profiles from the control-burned relict and no-burn-history plots (Fig. 2 and 3).

3) The nutrient levels of the old-burn appeared to be shifting toward those existing in soils from the area having no known history of burning.

Ponderosa pine seedlings as indicators of soil-nutrient differences did not exhibit the same sensitivity as lettuce plants. However, nutrient differences occurred between soils which were attributed to different time-of-burning history. This assay also gave a means of relating the lettuce bioassay results to native ponderosa pine.

The nutrient differences, indicated by ponderosa pine seedlings, between soils of different time-of-burning histories (Fig. 4) resulted in the following conclusions:

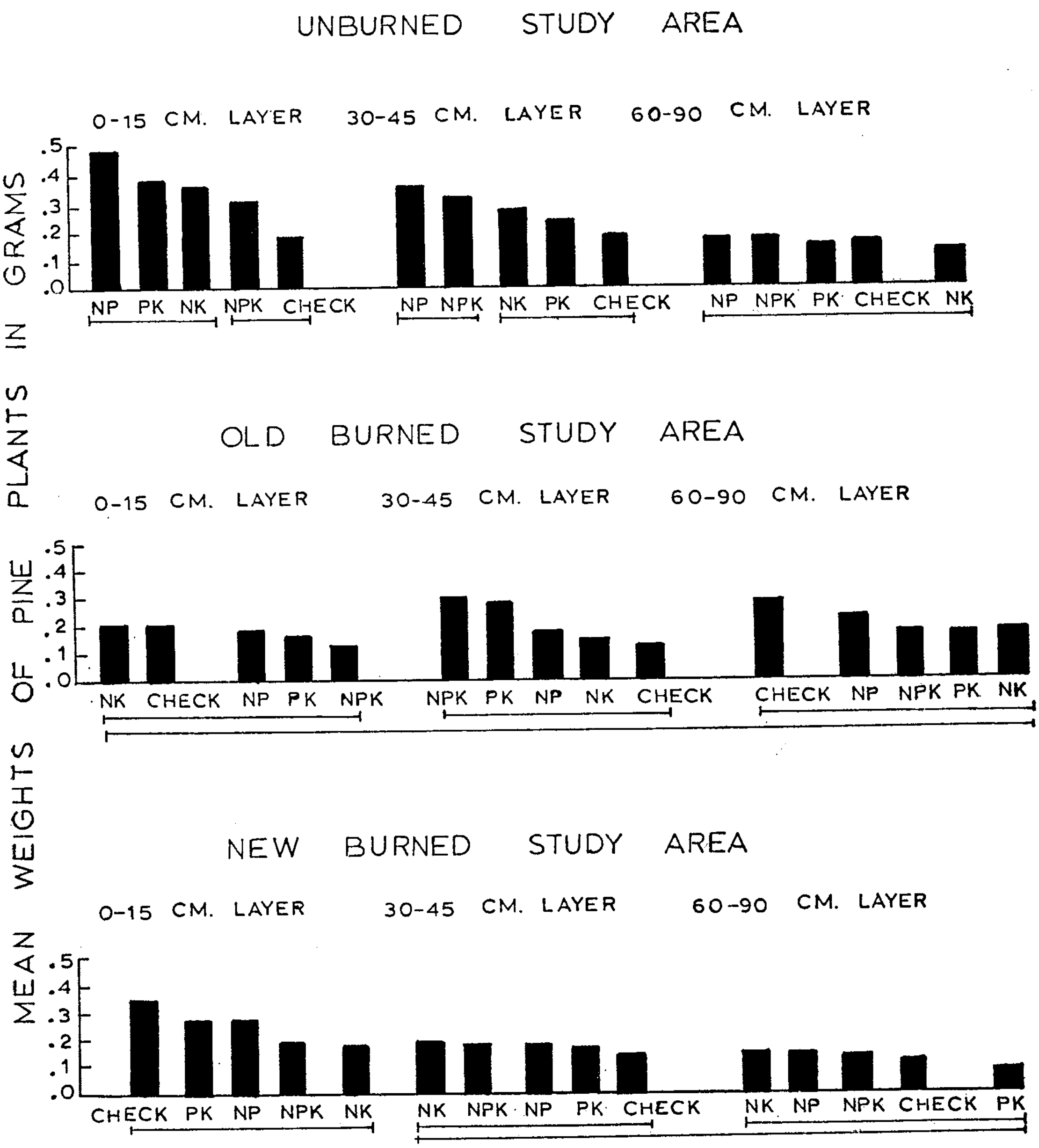

FIG. 4. Ponderosa pine seedling yields on soils collected from areas with three different histories of wildfire.

TABLE 1. Available phosphorus and nitrogen in soils collected 1 year after burning from three control-burned plots—expressed as parts per million in ovendry soil

Area	Depth (cm)	Phosphorus	Nitrogen
No-burn history	0–15	46.00	0.86
	15–30	0.85	0.36
	30–45	0.53	0.29
Relict unburned in old burn	0–15	48.00	1.00
	15–30	44.00	Trace
	30–45	0.94	Trace
Relict unburned in new burn	0–15	46.00	0.67
	15–30	0.34	Trace
	30–45	5.60	Trace

TABLE 2. Available phosphorus and nitrogen in soils from three depths from plots with different wildfire burn histories—expressed as parts per million in ovendry soil

Area	Depth (cm)	Phosphorus	Nitrogen
No-burn history	0–15	1.43	12.00
	30–45	0.73	3.20
	45–90	0.71	1.20
Old burn	0–15	0.71	3.20
	30–45	1.13	2.80
	45–90	1.00	2.80
New burn	0–15	1.59	33.00
	30–45	1.59	3.20
	45–90	0.75	2.80

1) The soils from each collection area again (as in the lettuce bioassay) showed unique fertility characteristics. Growth inhibition of ponderosa pine seedlings grown in soils given the NPK treatment from the 0–15-cm soil layer indicated a major difference between pine seedling and lettuce plant nutrient requirements.

2) The soils from the 0–15-cm layer collected from the unburned area had no apparent deficiencies in nitrogen, phosphorus, and potassium. However, there was a suggestion that enough potassium was present to inhibit growth.

3) Soils from all three layers in the old burn were low in nutrient availability.

4) Soils from the new burn had a higher level of nutrient availability in the 0–15-cm soil layer than in the two deeper layers. This was the main difference between soils from the new-burn and old-burn areas.

The following conclusions can be drawn from the chemical analyses on the soils from the three areas with different burn histories (Table 2):

1) The soils from each soil profile had individual and unique differences in nitrogen and phosphorous availability.

2) Analyses of the soil layers from all three soil-collection areas showed that differences existed in nitrogen and phosphorus within and between soils from the different collection areas.

3) Soils from the area most recently burned over by wildfire had a high nitrogen content in the surface 15 cm of soil, the source of which is unknown. The work of Fowells and Stephenson (1934) gives a possible explanation. This effect was not apparent, however, in the areas which were control-burned by fires of comparatively low intensity (Table 1) nor did this effect hold up, as shown by the nitrogen contents, in soils collected from the areas which had been burned over by wildfire many years ago.

DISCUSSION

Changes in the availability of plant nutrients from the soil, caused by wildfires of high intensity, varied with the time elapsed after burning. Such information contributes to our understanding of a fire-dependent environmental relationship that may exert a limiting influence on the regeneration of trees in a previously forested area. It would be an oversimplification to say that soil nutrient deficiencies were alone responsible for the absence of ponderosa pine regeneration in the areas studied. Berglund (1967) showed that initial germination and establishment in ponderosa pine was dependent on controlling extremes in temperature, wind, and available soil moisture. However, a study of 2-year-old ponderosa pine seedlings established in an old burn showed a 50% mortality rate over a 1-year period (Wagle, *unpublished data*). Drouth was the chief cause of this mortality, but nutrient deficiencies may have contributed to these losses.

Both of the burned areas studied were portions of very large burns that had once been covered by a ponderosa pine forest containing many large trees, representing high potential for the production of lumber and pulpwood, aesthetics and recreation, wildlife cover and habitat, and watershed and stream-source protection. The new burn shows no regeneration of ponderosa pine. The old burn has sporadic regeneration in a few situations, but at present it is mostly covered with herbaceous and small brush plants. Even attempts at planting the old burn with ponderosa pine seedlings and seeds, under a variety of site-preparation treatments, have resulted in almost 100% failure (Berglund 1967, Wagle, *unpublished data*). These large burns are numerous in the southwestern ponderosa pine type and will continue to occur until the problem of controlling wildfire before it reaches disaster proportions is solved.

The growth responses of the ponderosa pine seedlings grown in these soils under the same greenhouse environment indicate that changes in the plant nutrients available from the soil can influence growth in young ponderosa pine seedlings to the extent that other environmental factors, such as drouth, may become limiting, and thus may be one of the factors controlling or slowing the re-invasion of large burned-over areas by ponderosa pine. This information may prove useful as a guide to manipulating the soil environments (fertility) of large burned-over areas as one means of favoring the growth of established ponderosa pine seedlings. Survival potential of these seedlings thus would be increased. It has been well established that healthy, well-developed, growing seedlings are generally more resistant to environmental extremes than slow-growing, poorly developed seedlings.

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