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Environment & Earth Science

Highlights

- Long-Term Soil Fertility
- Causes of the Earth's Expansion
- Desorption to Remove Crude Oil
- Greenhouse Gases: Background Issues

Discovering Thoughts, Inventing Future

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Long-Term Soil Fertility Changes Following Thermal Desorption to Remove Crude Oil are Favorable to Revegetation Strategies

By Jake Mowrer, Tony Provin & Steve Perkins

Abstract- Heat treatment is effective for removing petroleum hydrocarbons from soil. However, high heat reduces the fertility of soils. This study determined the effect of temperature, and crude oil and salt additions on the fertility of four soils. Effects were assessed immediately after thermal treatment and following an equilibration/stabilization period. Soils were heated at four controlled temperatures (65, 300, 425, and 550°C) and also in an uncontrolled smoldering device, with 0 or 50 g kg^{-1}oil added and with 3 levels of salt solution added (0, 1, or 3 ms cm^{-1}). Soils were 'rapidly weathered' via wet / dry cycles at 37°C for five weeks. Initial changes in soil fertility were extreme enough to inhibit plant growth. Soil pH values were positively related to temperature, exceeding pH 8.5 at 550°C. The severity of changes was markedly reduced following incubations, showing that post heat treatment fertility will rebound with time and water.

Keywords: *thermal desorption, petroleum hydrocarbons, soil remediation, ecological restoration.*

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Long-Term Soil Fertility Changes Following Thermal Desorption to Remove Crude Oil are Favorable to Revegetation Strategies

Jake Mowrer [α], Tony Provin [σ] & Steve Perkins [ρ]

Abstract- Heat treatment is effective for removing petroleum hydrocarbons from soil. However, high heat reduces the fertility of soils. This study determined the effect of temperature, and crude oil and salt additions on the fertility of four soils. Effects were assessed immediately after thermal treatment and following an equilibration/stabilization period. Soils were heated at four controlled temperatures (65, 300, 425, and 550°C) and also in an uncontrolled smoldering device, with 0 or 50 g kg^{-1}oil added and with 3 levels of salt solution added (0, 1, or 3 ms cm^{-1}). Soils were 'rapidly weathered' via wet / dry cycles at 37°C for five weeks. Initial changes in soil fertility were extreme enough to inhibit plant growth. Soil pH values were positively related to temperature, exceeding pH 8.5 at 550°C. The severity of changes was markedly reduced following incubations, showing that post heat treatment fertility will rebound with time and water.

Keywords: thermal desorption, petroleum hydrocarbons, soil remediation, ecological restoration.

I. Introduction

Oil spills have the potential to introduce crude oil directly into soil resources where terrestrial petroleum exploration, extraction, or transport occurs (USEPA, 1999; Etkin, 2001). Adverse impacts of petroleum on soils include reduction or elimination of the capacity to support plant life through direct toxic effects (Atlas and Philp, 2005; Tang et al., 2011; Balseiro-Romero and Monterroso, 2014), alterations to hydraulic properties (Caravaca and Roldán, 2003; Ujowundu et al., 2011; Mowrer et al., 2021), and alterations to soil microbial and macro-invertebrate ecology (Hentati et al., 2013; Khan et al., 2018). These properties support proper ecosystem function and provisioning by soils, without which, the potential for cascading adverse effects on adjacent systems and on human health are increased (Jones et al., 2015; Lacalle et al., 2020). As a result, over $10 billion USD have been spent annually to clean and remediate these sites (Kontovas et al., 2010), and approaches to efficiently remediate oil-impacted soils are currently the subject of intense interest.

Thermal desorption (TD) treatment is an effective approach to removing oil from impacted soils through the controlled application of high heat to either combust or pyrolyze the petroleum hydrocarbon fraction (Gan et al., 2009). Smolder removal is similar to TD in the use of high temperature, but differs in that the process is less controlled. A smolder front is initiated in the soil mass through an initial igniting source while oxygen is continuously supplied to maintain that front, which progresses through the hydrocarbon fraction until it is consumed (Switzer et al., 2009). Both approaches require excavation of affected soil volume and *ex situ* application of the thermal treatment. Temperatures required to remove oil during the treatments are reported in the range of (100-900°C) for TD and (600-1100°C) for smolder removal (Switzer et al., 2009; Vidonish et al., 2018). The efficiency of the remediation process depends upon the temperature and duration or thermal application, the concentration of oil, the composition of the oil, and the physical and chemical properties of the soil (O'Brien et al., 2018; Vidonish et al, 2018). Salt content, organic matter, and sand are known to reduce the thermal conductivity of soils, while bulk density may increase it (Abu-Hamdeh and Reeder, 2000; Araruna, Jr. et al., 2004). Although salt content has not been studied in the context of thermal remediation of oil-impacted soils, thermal conductivity will play a role in efficiency of removal (Araruna, Jr. et al., 2004; Chen et al., 2020). Therefore, it is important to better understand the effect of co-impacts on soil of saline produced waters with oil at sites where petroleum hydrocarbons are released.

While the total petroleum hydrocarbons (TPHs) can be efficiently removed through thermal treatment via TD or smolder treatment, exposure to high heat alters soil physical, chemical, and biological properties whether oil is present or not (O'Brien et al., 2018). Many previous authors have suggested that these changes would reduce the capacity of soils to support plant growth, compared to soils not exposed to high heat. For instance, Ibrahimi et al. (2018) found that aggregation was increased in sandy soil but decreased in a soil with higher clay content following burning treatments. Ulery et al. (1993) reported changes in the texture of four forest soils in California from fine to coarse as a result of the fusing of smaller clay fraction primary particles into larger particles. Ketterings et al. (2002) reported increasing coarsening of texture with increasing temperature of a single Oxisol following slash and burn

Author α σ: Texas A&M Agri Life Extension | Department of Soil and Crop Sciences | College Station TX. e-mail: jake.mowrer@ag.tamu.edu
Author ρ: Chevron | Houston, TX.

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events in Sumatra, Indonesia. Alterations in mineralogy were also reported by these authors. Mowrer et al. (2021) reported changes to the shapes of water retention curve and to saturated hydraulic conductivity (Ksat) in three soils following application of high heat in the range of 65°C to 800°C. The authors (ibid) reported an increase in Ksat throughout the temperature range in soils containing appreciable clay content, a result consistent with shifting texture from fine to coarse due to fusing, but not precisely indicative of a negative change for soil function.

Several authors have suggested that the chemical properties of soils would also be altered for the worse, where revegetation following thermal treatment is the goal (Pape et al., 2015; O'Brien et al., 2017). Vidonish et al. (2016) were among the first to postulate that a residual deposition of char from the pyrolysis of TPHs would possibly enhance soil fertility. In this study, *Arabidopsis thaliana* and black-seeded lettuce (*Lactuca sativa*) treated via pyrolysis produced more biomass than untreated soils containing 16,000 and 19,000 mg oil kg^{-1} soil respectively. However, the authors' conclusion is confusing when considered with their reporting that both species in the study performed best in soils that never received oil. Vidonish et al. (2016) also detailed changes in soil combustion carbon (C), total nitrogen (N), nitrate-N (NO_3-N), phosphorus (P), and pH. The temperature of heat treatments (420°C and 650°C) were negatively related to C, N, and P, but positively related to pH in both soils. The authors described the fertility analyses as "standard" but did not specify whether P was measured as total or plant available. The pH in both soils rose from 7.2 and 7.4, to 11.1 and 11.9 respectively from untreated to incinerated at 650°C. It is not surprising that the incinerated soils performed poorly in supporting plant growth, as these pH values are far above the 5.5 - 7.5 soil pH range optimum for most plant species (Havlin et al., 2014).

Pape et al., (2015) reported changes in soil chemical properties following thermal exposure and smolder treatments in two soils. In this study, coal tar was artificially introduced at 80,000 mg kg^{-1} to an acidic loam and a "commercially available horticultural soil" prior to smolder treatment. The thermal treatments of air dry, 105°C, 250°C, 500°C, 750°C, and 1000°C were applied to soils without oil addition. No further details on the soil intrinsic properties were provided. The authors measured changes in pH, electrical conductivity (EC), organic matter, total and inorganic N, organic P and exchangeable calcium (Ca), Magnesium (Mg), potassium (K), sodium (Na), manganese (Mn), copper (Cu), and zinc (Zn) in the two soils heated to 5 TD temperatures in the range 105°C - 1000°C and 1 smolder treatment. They reported general increases in pH and EC with increasing temperature, consistent with Vidonish et al. (2016), and general decreases with all above nutrients. Smolder treated soil changes were generally similar to those of the more extreme TD temperatures. Based on the growth of red clover and red fescue on these soils, Pape et al. (2015)recommended a maximum TD temperature of 500°C when revegetation was a goal.

Glaringly missing from this developing body of investigations to date, especially from a soil fertility standpoint, are robust comparisons between multiple soils of contrasting properties with complete descriptions of the taxonomies of the soils, and chemical fertility properties of the soils prior to and following thermal treatments. Further improvements to this body of knowledge will aid in the successful revegetation of oil-impacted soils following TD or smolder remediation treatments. Therefore, the aim of the study described herein was to characterize the fertility related chemical changes in four soils as a function of soil properties, addition of oil, additions of salt, and temperature and type of thermal remediation approach. Also of interest in this study was the relative stability/transience of post TD and smolder treated soil chemical changes. Therefore, a simulated weathering study was conducted to evaluate to what degree post treatment changes in the chemistry of soil fertility were transient or permanent.

II. Materials And Methods

a) *Soils*

i. *Soil collection*

Four soils were collected for the study in the summer of 2019 (Table 1). A soil mapped as an Amarillo series (NRCS Soil Survey) was collected by front end loader from the top 25 cm in western Texas. A soil mapped as a Billings series was collected from the top 25 cm by hand in northwestern Colorado. A soil mapped as a Kettleman series soil was collected from the top 25 cm by hand in central California. A soil mapped as a Penwell series was collected from the top 25 cm by front end loader in western Texas.

ii. *Soil processing and preparation*

Soils were allowed to air dry for 24 hours on 3 x 6 m plastic tarps during the summer months of 2019. After drying, soils were mixed through turning and agitation in 200 L batches in a commercial 800 kg capacity cement mixer. After mechanical mixing, batches were hand blended using 45 cm shovels on top of plastic tarps. Mixed soils were then sieved through a 5 mm stainless steel screen mesh fitted onto a 1 m x 1 m wooden frame and transferred to labelled 20 L plastic buckets for storage until use in the following experiments.

iii. *Soil chemical and physical analysis*

A complete description of analytic methods used in this study are presented in Table 2.

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b) Experimental Design

i. Oil treatments

Oil additions were based on a single 5% TPH goal using an Arab Medium crude oil. The oil (450 grams) was added to the recently wetted soil in an identical manner as described in the water or salt solution additions. Following thorough mixing, the wetted soil and oil mixture was placed in covered aluminum storage trays. The TPH profile of the oil is presented in Table 3.

ii. Salt treatments

Nine kg of soil was placed in a 32 cm x 52 cm x 15 cm 18/8 stainless steel pan. Either deionized water or a sodium chloride salinity treatment was added at a rate of 450 ml per pan. The salinity treatments therefore included a 0g NaCl (control), a 5.75 g kg^{-1} NaCl kg^{-1} (1 mS cm^{-1}), or a 17.28 g NaCl kg^{-1} (3 mS cm^{-1}) addition. Each solution was introduced by pouring into an oval depression formed in the soil. Solutions were mixed into soils using stainless steel spoons. The soil was then covered for 24 hours and thoroughly remixed prior to oil additions, if applicable, else were directly transferred to the covered aluminum trays.

iii. Thermal treatments

Three methods of soil heating were used in this study, producing a total of 5 temperature treatments. The control treatment involved heating soils to 65°C in a Precision Quincy (Chicago, IL) forced air drying oven for 24 hours. All soils were, in fact, initially prepared in this manner. The 300, 425, and 550°C temperature treatments were then performed using a 189GFETLC Square Olympic Kiln (Olympic, WA). An additional smolder treatment used a custom-built smolder system utilizing a propane burner and an electric blower. The prepared soil treatments for the 65, 300, 425, and 550°C were individually remixed during transfer back to the 32 x 27 x 15 cm 18/8 stainless steel pans. Thermocouples were placed in the center of the kiln heated treatments to determine the time required to achieve and maintain a consistent temperature treatment throughout the entire tray for 2 hrs.

The custom smolder unit was designed using 1.25 x 15 x 28 cm A36 steel plates welded in a hexagon pattern to a 0.95 cm thick A36 plate (Figure 1). A removal door allowed for placement of thermocouples at various areas within the smolder unit, and allowed for easier recovery of soil. A perforated A36 steel pipe placed through the center of the smolder unit floor served to allow air and heat to be distributed under a 100 x 100 stainless mesh (0.11 mm opening). A 130,000 btu propane burner was fitted to allow for both burner operation and air flow into the perforated pipe. Oil-containing soil was uniformly spread across the stainless-steel mesh prior to ignition of the propane burner. The burner was operated at full capacity until the lower-placed thermocouples indicated an internal temperature of 500°C. At this point, the propane burner was turned off, though forced air flowwas continued until the upper thermocouples had both achieved 500°C and then cooled to 80°C.

iv. Post-thermal soil processing

Each soil treatment was pulverized after the thermal treatments using an AgVise soil grinder with a series of 12 hardened steel hammers spinning at 1750 rpm. A 2mm mesh sieve was used to screen the soil before being stored for chemical analysis and/or rapid weathering simulation studies.

v. Rapid weathering incubation study

To develop a better understanding of eventual long term chemical equilibria of soils post thermal treatment, a study was conducted to simulate natural wet/dry and cooling/warming cycles over a five-week period. Soil (100 g) from each treatment and 50 mL distilled water were placed into 250 mL plastic containers with screw top lids. Three replications of each treatment were performed. The containers were then placed into an incubator set to 37°C for 24 hours, after which pH and EC measurements were made on each sample. Following measurement, the soils were placed back into the incubator for 3 more days. Then the samples were removed and placed on a laboratory benchtop in front of a stationary fan to dry for an additional 3 days. Room temperature was maintained at 21-23°C at all times. Once dry, the samples were re-wet with 50 mL distilled water and the cycle repeated for an additional four weeks. Samples were analyzed for plant available nutrients and micronutrients for comparison of changes from immediate post treatment nutrient availability.

c) Statistical Analysis

i. Soil chemical analysis results

For all Mehlich III (MIII) and DTPA extractable nutrients, pH, and electrical conductivity (EC) results, a global ANOVA including all soils was performed using the SAS software (SAS; Cary, NC) to examine the effects of each of the factors in the experimental design, as well as their interactive effects. Differences between treatments immediately following treatment, and differences between treatments following the five-week incubation period were examined. Each soil was examined separately using the following model in the GLM procedure.

y = temperature oil salt temp* oil temp* salt oil*salt temp* oil* salt

The results for probability of treatment and interactive effects (p-values) are presented for all factors in the treatment structure with the level of significance set at $\alpha = 0.10$. However, p-values < 0.15 are included for potential interest in future studies. Regression analysis was used following the ANOVA to determine

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whether the direction of significant effects (slope) was positive or negative. Differences between soil chemical properties before and after incubation were analyzed for significance using a paired t-test in the SAS software via the TTEST procedure.

ii. *Predictive modelling of changes in soil properties*

Multiple linear regression analysis was performed using the GLM procedure in the SAS software to develop a predictive equation using only the simple treatment factors (i.e. no interactions) and the soil properties clay and sand content. The regression was performed on the immediate post-treatment soil state to develop an understanding of immediate changes caused by thermal treatments. Next, regression analysis was performed on final results of the incubation trials to estimate and predict the relationship between the treatments and soil texture on the chemical equilibrium of soil fertility following replacement *in situ* on the landscape. For this analysis, all soil results were included in one set to improve predictions accounting for outcomes as a function of soil texture. Models for soil fertility parameters that did not result in a probability of < 0.05 or coefficient of determination (r^2) > 0.500 are not reported, with the single exception of soil pH. Models for soil pH are included here due to its fundamental influence on soil fertility, its frequent inclusion in past studies, and its value towards the developing body of literature on this subject.

III. Results

a) *Post Thermal Treatment Changes in Soil Fertility*

Soil was a significant parameter in the ANOVA model for all treatments. Therefore, this section is arranged by soil, which allows for an examination of the differential responses between soils. The final subsection on predictive modelling provides an examination of the results across all soils in the study. Soil nutrient sufficiency ranges for plant growth and levels of concern are provided for reference in Table 4.

i. *Amarillo soil*

Soil fertility analysis of all treatments applied to the Amarillo soil are presented in Table 5. Texture results for the Amarillo soil (sandy loam) were 75 % sand, 9 % silt, and 16 % clay. Effects and interactions related to changes in AM soil chemical properties as a result of thermal, oil, and salt treatment combinations are presented in Table 6. Soil pHwas affected by temperature, oil, and salt treatments, as well as the interactions between temperature and oil and temperature and salt additions. Soil pH was positively related to temperature, but negatively related to oil and salt additions. Increases in pH with heat were likely a product of the oxidation of Ca released from the mineral phase during heating. The greatest increase in pH from the control soil was 1.53 pH units from 7.80 to 9.33 in the 550°C oil-receiving soil with 3 mS cm^{-1} salt solution added. Three pH values in soils heated to 550°C were raised above the pH level of concern (8.5) in Table 4. There were some decreases in pH where oil was added in lower temperatures, the greatest of which was observed to be 6.66 pH in 300°C oil-receiving treatment with 3 mS cm^{-1} salt solution added.

Soil EC following thermal treatments was affected only by salt addition. However, in those soils receiving the most concentrated salt solution (3 mS cm^{-1}), EC was decreased from 2710 µS cm^{-1} in the control soil to 1096 mS cm^{-1} in the 550°C treatment (Table 7). This pattern was closely aligned with that of Na. This suggests that Na may have volatilized at high heat, potentially reducing plant stress from soil salinity. The final concentration of Na was, in fact, reduced to 376 mg kg^{-1} soil and below the level of concern (400 mg kg^{-1}) in Table 4.

Extractable nutrients were affected in different ways by the different treatments. Some nutrients increased with temperature of heating in TD treatments (e.g. P, K, Ca, S, Fe, Zn, and Mn), while other nutrient changes were not directly related to temperature (Table 6). Nutrients that are increased with heat are similarly more aggressively released from organic and mineral phases as temperatures increase. Plant available P was increased from 16 mg kg^{-1} to levels as high as 86 mg kg^{-1} (Table 5), well above the critical level of 50 mg kg^{-1} (Table 5). This indicates a shift from substantial deficiency to more than sufficient level. Oil additions resulted in decreases in P, K, Ca, Na, Fe, Zn, and Mn(Table 6). Salt additions positively affected Na and negatively affected Fe. Temperature and oil interactions were present for P, K, Ca, Na, and Fe. Temperature and salt interactions were present for Na and Fe.

ii. *Billings soil*

Billings soil fertility analysis is presented in Table 7. Texture results for the soil were 51 % sand, 29 % silt, and 20 % clay, placing it in the loam textural class (Table 1). Summary of ANOVA results for effects and interactions related to changes in BL soil chemical properties as a result of thermal, oil, and salt treatment combinations are presented in Table 8. Soil pH was affected by temperature, oil, as well as the interactions between temperature and oil addition, though not affected by salt additions as was the case with the Amarillo soil. The effect on pH was positively related to temperature, and rose substantially above the level of concern (pH 8.5) in all 550°C treatments. Soil EC was negatively affected by temperature and oil addition, but positively related to salt addition.

Some nutrients increased with temperature of heating in TD treatments (P, K, Ca, Fe, Zn, and Mn). However, S decreased while other nutrient differences(Zn, Mn, Cu) were not related to temperature. Oil additions exerted negative effects on P, K, Ca, Na, Fe, Zn, and Mn. Salt additions had a positive effect on

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Na and a negative effect on Fe. Temperature and oil were interactive effects for P, K, Ca, Na, and Fe. Temperature and salt were interactive effects for Na and Fe.

iii. *Kettleman soil*

Texture results for the Kettleman soil were 49 % sand, 19 % silt, and 32 % clay (sandy clay loam). Post thermal treatment soil fertility results are presented in Table 9. Soil pH was negatively related to temperature, oil addition and salt addition (Table 10). This pH relationship is opposite of those in the Amarillo and Billings soils. Clay content in the Kettleman soil is not dissimilar from the Amarillo soil, suggesting that minerology is a stronger influence on these differences than texture. Initial pH values are very close for all three soils (Amarillo, Billings, and Kettleman), as is plant available Ca. Total calcium in the mineral phase available to form oxides and hydroxides (CaO and $Ca(OH)_2$) may differ between the soils, though the alkaline pH in the untreated soil suggests the presence of substantial calcite ($CaCO_3$). Soil EC following thermal treatments was negatively by temperature and oil, but positively affected by salt addition.

Effects and interactions related to changes in Billings plant available nutrients as a result of thermal, oil, and salt treatment combinations are presented in Table 10. Some nutrients increased with temperature of heating in TD treatments (P, K, S, Fe, and Zn), while others (Ca, Mg, Na, and Cu) were negatively affected. No other nutrient changes were related to temperature. Of note are the increases in MIII P from the control which bring the level from half of the critical value (Table 4) to a concentration above the sufficiency level for plant growth. Oil addition resulted in negative effects on P, K, Ca, Mg, S, Na, Zn, and Cu. Salt additions resulted in positive effects on Na only. Temperature and oil were interactive for K, Ca, Mg, S, Na, and Cu. Temperature and salt were interactive for Na only. Although not related to the treatment effects, Mn was increased from 3.9 mg kg^{-1} in the control to above the level of concern 30 mg kg^{-1} in four of the treatments (Table 9).

iv. *Penwell soil*

Texture results for the Penwell soil were 99 % sand, 1 % silt, and 0 % clay placing it in the sand textural class (Table 1). Soil fertility results for all treatments applied to this soil are presented in Table 11. Results of ANOVA are presented in Table 12. Soil pH was negatively related to temperature, oil and salt. This result differs from that of previous studies, and is likely due to the absence of clay colloids with exchange sites, and the low amount of exchangeable bases such as Ca and Mg. Soil EC was only affected by salt additions.

Some nutrients increased with temperature of heating in TD treatments (P, K, Mg, S, and Fe), while other nutrient changes were negatively affected (Na, Zn, and Cu) or not related to temperature (Table 11). Oil addition was responsible for negatively affecting plant available P, K, Ca, Mg, S, Na, and Cu. Salt additions were responsible for positive changes in K, Na, and Zn, and negative changes in Ca and S. Temperature and oil interactions affected P, K, Mg, S, and Na. Temperature and salt interactions affected changes in Fe and Zn. Oil and salt interactions affected changes in S and Na.

Changes in K concentrations between the control (47 mg kg^{-1}) and the 550°C treatments (106-178 mg kg^{-1}) were substantial enough to lift the status from deficient to sufficient (Table 4). The range of Cu differences (0.2 to 1.1 ppm) are substantial enough relative to the sufficiency range to have an influence over plant growth performance. The high salt treatment resulted in a MIII Na concentration of 896 mg kg^{-1}. Thermal treatment at 550°C following oil addition reduced this level to 389 mg kg^{-1}, and below the level of concern (Table 4).

b) *Rapid weathering incubation study*

The rapid weathering simulation study was conducted to estimate relative changes with naturally occurring fluctuations in environmental conditions in a short time period, and showed that soil type was a significant effect on soil fertility chemical changes between treatments following the weathering simulation. Soil pH and EC monitoring throughout the five-week period for the controlled TD treatments were used to provide evidence of an approach to chemical equilibrium. Changes in the pH and EC at weekly monitoring events are reported. Final concentrations of plant available nutrients (and Na) for all TD and smolder treatments are also reported. Results are presented by soil.

i. *Amarillo soil*

Weekly measurements of soil pH during the five-week incubations indicate that the 'as received' (65°C) soil was not substantially affected by salt addition (Figure 2a). Over the course of the incubation period, the pH decreased in the control soil by 0.2 units from 7.7 - 7.5 pH. The difference was of very small practical importance towards the goal of long-term revegetation, and may be explained by the acidification caused by mineralization of organic N to ammonium-N (NH_4-N) and subsequent nitrification of NH_4-N to nitrate-N (NO_3-N) promoted by 6 successive wet dry cycles (Haynes and Swift, 1989).

The 300°C TD treatments generally decreased pH values initially in this soil by approximately 0.2 pH units, while additions of oil and TD caused more substantial reductions from 7.6to6.6 pH (Figure 2b). After five weeks, soil pH values increased to between 7.2 and 7.8 pH. Heating to 425°C and 550°C resulted in much more substantial changes in soil pH (Figures 1c and 1d). At 425°C, when salt was added to soils, pH was elevated as much as 1.5 pH units. At 550°C, the initial pH value for the 3 µS cm^{-1} treatment was elevated

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to pH 10, a difference of > 2 units. In all cases, the treatments receiving oil prior to TD were found to be lower in pH than those parallel treatments receiving no oil. Following the incubation period, the weekly degree of change approached zero for all treatments except for the oil receiving 550°C TD treatment. This indicates that a state of equilibrium is either near or already present for this soil. All final pH values were within 0.5 units of the initial control soil.

Plant available nutrient changes during the incubations in the control were relatively minor in magnitude (<10%) for P, K, and Ca. Changes between conditions immediately following thermal treatment and those following incubation were most substantial in those treatments receiving oil. For example, reductions in P concentrations were observed at 425°C and 550°C. In most cases where reductions occurred, levels remained above those of the control soil. For example, post TD treated soil at 550°C without salt addition reached 63 mg P kg^{-1} soil and settled at 41 mg P kg^{-1} soil following the incubation period (Tables 5 and 13). This is more than twice the final P level of the control soil (20 mg kg^{-1}). Soil K levels continued to increase during incubation in most treatments involving thermal treatment, with the exception being oil receiving soils TD treated at 425°C. Soil Mg, S, Na, Fe, Zn, Mn, and Cu were generally, but not universally, observed to decrease over the incubation period.

ii. *Billings Soil*

Weekly measurements of soil pH made during the incubation indicate that the control Billings soil was not substantially affected by salt addition (Figure 3a). There was an approximate 0.5 unit rise from 7.6 to 8.1 pH over the five-week incubation period that is not insubstantial, and in this range could result in a problem with plant growth. The rise may be an artifact of the cycling of saturated and unsaturated conditions of the study contributing to the dissolution and subsequent oxidation of calcium species in the soil. Those soils heated to 300°C followed the same pattern of rise over the incubation period (Figure 3b). However, the oil receiving treatments all remained lower in pH than the non-oil receiving counterparts at that temperature. All treatments within the 300°C TD temperature settled at values between 7.5 and 8.0 pH.

The 425°C TD treatments resulted in a response pattern similar to that of the 300°C treatments with the exception of the high salt solution (3 ms cm^{-1}) treatment, which had initially increased to 9.1 pH (Figure 3c). All treatments within the 425°C temperature set eventually settled to values between 7.5 and 8.0 pH following the incubation period. All treatments within the 550°C temperature setinitially increased substantially with oil and salt addition from 7.5 pH in the control to values that ranged from 9.5 to 10.5 pH (Figure 2d). Values above 8.5 pH are of definite concern for plant growth (Table 4). However, the final values decreased to a range between 7.8 and 8.4 pH. This outcome clearly indicates that a final stable equilibrium in the field would be much more suitable for plant growth than initial post TD treated values would suggest.

Plant available nutrients changed over the course of the incubation in the Billings soil. Soil P values, which had increased with increasing temperature immediately following thermal treatments, further increased in the 300°C and 425°C TD and the smolder treatments where oil was added (Tables 7 and 14). Soil P decreased in all other treatments following the incubation period. Soil K increased over the incubation period except in the non-oil receiving treatments heated to 300°C and 425°C. Soil Ca and S increased in all thermal treatments except the non-oil receiving 300°C treatment. Micronutrient status generally decreased over the incubation period.

iii. *Kettleman Soil*

Weekly measurements of soil pH made during the incubation indicate that the 65°C treatment for Kettleman soil was decreased initially as much as 0.4 pH units upon the addition of salt solutions (Figure 4a). There were individual sampling events that indicated further decreases to substantially lower pH values with increasing salt concentration. However, all salt treatments at 65°C eventually converged to values between 7.5 and 7.7 pH. There was a small change between the initial and the final pH values at five weeks, though these would have little practical consequence in revegetation efforts. It is worth noting that all temperature treatments exhibited the same pattern of pH decrease at the two-week measurement event, and that the no salt (0 mS cm^{-1}) and no oil treatment was the only one for Kettleman soil to not exhibit a decrease in pH at this time during the incubation (Figures 3a - 3d).

Simple heating to 300°C decreased pH values initially in this soil by ~0.5 pH units, while additions of oil followed by TD treatment at 300°C resulted in decreases of 1.0 pH units or more. This is very similar to the effect observed in the Amarillo and the Billings soils. After five weeks, values for each treatment rose ~0.5 pH units to between 7.1 and 7.9 pH (Figure 4b). The pattern for this temperature in this soil over the course of incubations did not indicate that a near equilibrium chemical state had been achieved over the incubation period. Heating to 425°C resulted in similar soil pH changes as the 300°C treatment at the beginning of the incubation period. However, by the end of the incubation period, all values were stable for the last two measurement events at 4 and 5 weeks (Figure 4c). At 550°Cthe initial pH value for the 3 μS cm^{-1} treatment was elevated to 8.5 pH, a difference of 1.5 units. In all cases, the treatments receiving oil prior to TD were found to be lower, or not significantly different, in pH than those parallel treatments receiving no oil. Following the five week

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period, the weekly change approached zero for all treatments. This indicates that a state of equilibrium was near or attained for this soil. All final pH values were within 0.5 units of the initial untreated Kettleman soil.

The post TD treatment incubation process resulted in substantial changes in many plant available nutrients for the Kettleman soil. Extractable P decreased in most treatment combinations at the 425°C and 550°C temperatures, but remained above the control soil following the incubation period (Table 15). Soil K, Ca, and Mg nearly uniformly increased over the five-week period at the higher temperatures and for the smolder treatment. Sulfur decreased in most treatments below 550C. All micronutrients (Fe, Zn, Mn, and Cu) generally decreased during the incubation for higher temperatures, but increased in some lower temperature treatments (Table 15). Soil Na was most substantially decreased at lower temperatures, increased in the smolder treatment, and exhibited relatively small changes over the incubation period for higher temperatures.

iv. *Penwell Soil*

Weekly measurements of soil pH made during the incubation indicate that the 65°C treated Penwell soil were not affected by salt addition initially (Figure 5a). There was negligible change between the initial values and the final values at five weeks for pH in the 65°C treatments. All three salt treatments were approximately pH 8.0. Heating to 300°C did not affect pH values initially in non-oil receiving treatments (Figure 5b). However, additions of oil and TD together caused a more drastic reduction from ~ pH 8.0 to pH 5.7 in the 0 µS cm^{-1} treatment. Additions of 1 and 3 µS cm^{-1} salt solutions under went less severe decreases to ~ pH 7.0. This is a dissimilar pattern to that of the other three soils in the study. The Penwell soil has the highest percentage of sand of all three soils and no clay fraction (Table 1). It is possible that heating will result in a different reaction in the sand fraction than in a soil with more clay content. After six weeks, soil pH in the oil treated soils heated to 300°C did not converge to a similar value as those soils not receiving oil (Figure 5b). This is also a dissimilar pattern to that found in the other three soils. However, this may be explained by the exceptionally poor efficiency of oil removal at 300°C in this soil. Unpyrolyzed oil was clearly present in the Penwell soil post TD at 300°C.

Heating to 425°C and 550°C produced similar effects to those observed in the Amarillo and Billings soils in the initial changes following TD (Figures 4c and 4d). Heating alone at 425°C resulted in a 0.6 pH decrease and a 1.0 pH decrease in the 550°C compared to the control soil. Increasing salt additions increased pH ~ 0.5 and 1 unit respectively. Oil additions decreased pH 1 - 2 units when compared to the corresponding salt treatment. In all cases, the treatments receiving oil prior to TD were found to be lower in pH than those parallel treatments receiving no oil. Final pH values ranged from 0 to 2 pH units difference from the initial control soil (Figures 4a-4d). For the final three weekly measurement events period, the change approached zero for all treatments. This indicates that a state of equilibrium was either attained or close at hand.

The post TD treatment incubation process resulted in substantial changes in many plant available nutrients for the Penwell soil. Soil P, K, Ca, Mg, and S generally increased following incubation with few exceptions (Table 16). Micronutrients were generally decreased in all treatments, though to a lesser degree than the other three soils.

IV. Discussion

The current study evaluated the effects of temperature, oil addition, and salt addition to four soils of contrasting properties and found that pH was positively affected by temperature in two soils and negatively affected by temperature in two other soils (Tables 6, 8, 10, and 12). Addition of oil at 50 g kg^{-1} soil and addition of salt solutions (1 or 3 mS cm^{-1}) had negative effects on soil pH. The magnitude of the effect also differed between soils. Therefore, multiple linear regression analysis was used to develop a model of how pH (and the other fertility parameters measured in this study) were related to the treatments applied and to the textures of the soils.

Previous studies have reported soil pH changes following exposure to high heat through naturally occurring fires or through TD and smolder remediation treatments. Badia et al. (2003) reported a 0.6 pH unit decrease in soil following a forest fire at 250°C, and increases of > 1.0 pH units for soils exposed to 500°C. Vidonish et al. (2016) observed increases of ~1.0 pH unit for two oil-impacted soils receiving TD remediation to 420°C and ~4.0 pH units at 650°C. Pape et al. (2015) observed soil pH increases of ~ 1.5 pH units in two soils receiving thermal exposure at 500°C and 3.0 - 4.0 pH units in the same two soils receiving smolder remediation treatments. Soil EC increased with increasing temperatures in both soils.

Vidonish et al. (2016) reported soil P increased from 3 to 17 mg kg^{-1} in one unidentified soil following oil addition. This value increased to 65 mg kg^{-1} following TD treatment at 420°C but decreased to 4 mg kg^{-1} at 650°C. In another unidentified soil from Arizona, P decreased from 2 to <1 mg kg^{-1} at all temperatures. Pape et al. (2015) reported a moderate P increase in a "commercially available horticultural soil" through 500°C TD treatments and reductions at higher temperatures. They also reported consistent P decreases at all temperatures in an "acidic loam" soil. The same authors further reported decreases in soil K and Na with

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increasing temperatures in both soils. Pape et al. (2015) evaluated smolder remediation of oil-impacted soils as well, with results for many soil nutrients consistent with those for the highest thermal remediation temperatures (750-1000°C). However, no oil was added to the controlled thermal treated soil, so the comparison is not direct.

From the small number of studies on TD and smolder remediation, it is clear that soils of different intrinsic and dynamic properties exhibit different soil fertility responses. Therefore, the efforts of this study to evaluate the influence of soil physical properties, TD temperature, oil, and salt additions represent a first step towards establishing the relationships between these parameters and the fertility outcomes for thermal remediated oil-impacted soils. Pape et al. (2015) reported on the effects of smolder treatment on a soil receiving coal tar (80,000 mg kg^{-1}) compared with a range of temperatures of controlled thermal treatment (105°C - 1000°C) in two soils with no added TPH. Their results indicated that smolder treated soil outcomes were most similar to those of the two highest temperatures (750°C and 1000°C). In the current study, the soil fertility outcomes for smolder treated soils were most frequently (though not uniformly)aligned with outcomes from oil-impacted soils thermally treated at 300°C.

Multiple linear regression analysis for immediate post thermal treatment changes in soil properties follow (Figure 6). All models in the following descriptions were significant at $p < 0.0001$. The regression model for soil pH change was well described by temperature (°C), sand (%), clay (%), oil addition, and salt addition ($r^2 = 0.4554$). Soil EC changes were well described by sand, clay, oil, and salt, but not temperature ($r^2 = 0.551$). Changes in soil extractable P were well described by temperature, sand, clay, and oil addition, but not salt ($r^2 = 0.555$). Changes in soil extractable K were related to temperature, sand, clay, oil, and salt ($r^2 = 0.842$). Changes in soil extractable Na were well described by temperature, sand, clay, oil and salt ($r^2 = 0.770$).

In this study, using four well described soils, temperature had a positive effect on soil pH, P, and K, a negative effect on Na, but was not an important effect for EC (Figure 6). Oil addition followed by TD treatment had a negative effect on soil pH, EC, P, K and Na. Salt additions had a positive effect on soil pH, EC, K, and Na, but was not an important effect on P. Soil clay content had a negative effect on soil pH, EC, and Na, but a positive effect on P and K.

Changes in other soil fertility parameters were not well related to the treatments or to soil texture. The low coefficient of determination (r^2) for pH, indicating that the model accounts for less than half of the variability in the results, implies that other factors are responsible for pH changes than those investigated here. It is very likely that the mineralogy of a soil, exchangeable aluminum, and calcium carbonate content will be among the most important to investigate in future studies.

No study to date has attempted to evaluate the stability/transience of soil chemical changes following thermal remediation. While previous studies have reported concerning rises in pH and substantial losses in nutrients, this study has developed results that provide a different narrative. In all soils and applied treatments, initial pH elevations that were in some cases substantially above the level of concern of 8.5 (Table 4), returned to < 8.5 pH within three to five wetting and drying cycles. This is an important result that indicates even the most severe increases in soil pH (<10.0) are mitigated by water and time to acceptable levels for revegetation and restored ecosystem function (Figures 1-4).

Multiple linear regression analysis of final equilibrium soil fertility status following the simulated soil weathering incubations can be used to better understand the chemical equilibria of soils after return to the site of excavation follow (Figure 7).All models in the following descriptions were significant at $p < 0.0001$. Soil pH was positively related to temperature and negatively related to oil ($r^2 = 0.444$). Soil EC was negatively affected by temperature, oil, and sand, and positively affected by salt and clay. Soil P was positively affected by temperature, sand, and clay, and negatively affected by oil. Soil K was positively affected by temperature, sand, and clay, and negatively affected by oil. Soil S was positively affected by temperature and oil, but negatively affected by both sand and clay. Soil Na was negatively affected by temperature, oil, sand, and clay, but positively affected by salt addition. Soil Mn was negatively affected by temperature, and positively affected by sand and clay. Finally, soil Cu was negatively affected by temperature, and positively affected by oil, sand, and clay content.

Notable among the findings regarding the stability of post thermal remediation fertility changes is the mitigation of extreme pH values after a small number of wetting and drying cycles. Previous studies reported increases in soil pHto well above the level of concern (Table 4) following high heat exposure (Pape et al., 2015; Vidonish et al., 2016). Equally important are the indications that both soil P and K may be increased, rather than decreased, as reported by the same studies. This outcome indicates that TD treatment of oil-impacted soils improves fertility, not simply compared with the highly toxic oil-impacted soil as reported by Vidonish et al. (2016), but also compared to the unimpacted soil. This outcome was observed in all four soils investigated in the current study. Finally, high salt contents also appear to be mitigated, improving the chances of successful revegetation in soils where

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salinity or impacts with brine-containing produce waters are present.

V. Conclusion

The initial chemical changes in soils following TD treatment to reduce TPH content of impacted soils is important in determining only the suitability of initial conditions for revegetation of soils returned to their original sites. These changes to the chemical properties of soils associated with fertility can be substantial enough to constrain or prevent revegetation efforts. However, many of the previously reported post-thermal treatment (TD or smolder) changesare very likely transient, as demonstrated in the current study. Substantialchanges continue to occur over time following fluxes of water and temperature until a new and stable soil chemical equilibrium is established. These changes are likely to be favorable to revegetation strategies. Therefore, it is vitally important to understand what this state will be in order to plan for long-term successful revegetation.

Of particular interest in this study were the mitigation of extreme pH increases over three to five wetting cycles, as well as the increases in plant available P and K important for successful establishment of rooting systems and early growth of plants in revegetation efforts. High salt contents also appear to be reduced following TD remediation of oil impacted soils. The outcomes from this study provide a better understanding of the final equilibrium chemical state of the soil following return to the landscape. The study does not predict the time required to reach equilibrium under natural conditions, but rather the relative magnitude of changes that will occur. Finally, soil type and texture differences strongly influenced plant available nutrient changes between the treatments imposed (e.g. temperature, oil and salt), and such differences should therefore remain a central factor in decision-making processes for remediation and revegetation projects.

Conflict of Interest

The authors declare no conflict of interest.

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Figures and Tables

Table 1: Soils included in the study, their taxonomic class, texture, and textural class

Soil Series	Taxonomic Class (NCSS*)	Texture (% sand - silt - clay)	Textural Class
Amarillo (AM)	Fine-loamy, mixed, superactive, thermic Aridic Paleustalfs	75-9-16	Sandy Loam
Billings (BL)	Fine-silty, mixed, active, calcareous, mesic Typic Torrifluvents	51-29-20	Loam
Kettleman (KT)	Fine-loamy, mixed, superactive, thermic Typic Haplocambids	49-19-32	Sandy Clay Loam
Penwell (PN)	Siliceous, thermic Ustic Torripsamments	99-1-0	Sand

Table 2: Soil chemical analytic methods, brief descriptions, and analytic method references

Soil Parameter	Method Description	Reference
Phosphorus (P) Potassium (K) Calcium (Ca) Magnesium (Mg) Sulfur (S) Sodium (Na)	Plant available nutrients. Extraction with Mehlich III (MIII) followed by analysis by Inductively Coupled Argon Plasma Atomic Emission Spectrometer (ICP-AES).	Mehlich, (1978) Mehlich (1984)
Iron (Fe) Zinc (Zn) Manganese (Mn) Copper (Cu)	Plant available micronutrients. Extraction with DTPA followed by analysis by ICP-AES.	Lindsay and Norvell (1978)
Soil pH	2:1 soil:water by mass ratio using benchtop meter and glass ball pH probe	Schofield and Taylor (1955)
Electrical conductivity (EC)	Total salts by electrical conductivity using a benchtop meter and probe.	Rhoades (1982)
Total Petroleum Hydrocarbons (TPHs)	Analysis of an n-pentane extraction using gas chromatography (GC) followed by flame ionization detection (FID).	TNRCC method 1005 (2001)
Soil Texture	Particle size fraction of sand, silt, and clay composition of soils by Bouyocous hydrometer method	Day (1965)

Table 3: Results for the analysis of TPH and fractions of the Arab Medium crude oil used in this study and resultant TPH and fractions added to soils in 5% oil addition treatments. nC = carbon chain length fraction. TPH = total petroleum hydrocarbons

	nC6 - nC12	nC12 - nC28	nC28 - nC35	TPH
Crude oil (mg kg^{-1})	240,000	270,000	87,000	597,000
5% treatment (mg oil kg^{-1} soil)	12,000	13,500	4,350	29,850

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Table 4: Soil testing nutrient critical values and levels of concern (Texas A&M AgriLife Extension Soil, Water, and Forage Testing Laboratory, College Station, TX)

Parameter	Method	Units	Critical Value	Level of Concern
pH	2:1 H_2O:soil	-	<6.0 for most	>8.5
phosphorus	MIII	mg kg^{-1}	50	125
potassium	MIII	mg kg^{-1}	125-175*	--
calcium	MIII	mg kg^{-1}	180	--
magnesium	MIII	mg kg^{-1}	50	500
sodium	MIII	mg kg^{-1}	**	400
sulfur	MIII	mg kg^{-1}	13	***
iron	DTPA	mg kg^{-1}	4.25	--
zinc	DTPA	mg kg^{-1}	0.27-0.81*	40
manganese	DTPA	mg kg^{-1}	0.16	30****
copper	DTPA	mg kg^{-1}	1	1.5*****

**crop yield and species dependent*

***undesirable in most soil/cropping systems*

****high levels of sulfur can create problems for select grazing livestock*

*****when soil pH values are below 5.5*

******species dependent and when soil pH values are below 6.5*

Table 5: Soil fertility analysis for Amarillo soil as affected by thermal treatment with and without oil addition at 50 g kg^{-1} by mass, and with and without addition of salt solutions at 1 and 3 ms cm^{-1}. SM = smolder treatment

Amarillo Soil - Post Thermal Treatment Soil Fertility

Thermal Treatment	Oil g kg^{-1}	Salt mS cm^{-1}	pH	EC µS cm^{-1}	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
					mg kg^{-1}									
65°C	0	0	7.80	123	16	357	5608	216	13	42	1.1	1.1	2.5	0.24
65°C	0	1	7.86	465	15	360	5823	210	15	406	2.1	2.1	5.6	0.35
65°C	0	3	7.93	2710	14	347	5467	194	12	979	1.5	1.9	4.9	0.31
300°C	0	0	7.52	431	72	366	5842	166	83	49	5.2	1.7	9.0	0.48
300°C	0	1	7.76	1506	67	388	5962	163	77	350	8.0	2.7	16.1	0.59
300°C	0	3	7.96	2243	72	449	6311	162	79	953	7.6	4.2	20.9	0.73
300°C	50	0	6.73	131	23	111	3201	68	54	17	1.9	0.2	3.9	0.13
300°C	50	1	6.89	411	34	201	4616	90	90	189	4.9	0.4	9.3	0.26
300°C	50	3	6.66	1029	50	311	5533	109	167	768	13.0	1.2	15.5	0.50
425°C	0	0	7.65	245	78	606	8485	150	100	60	6.8	1.7	3.0	0.17
425°C	0	1	7.95	1182	83	683	9746	143	105	274	12.1	2.9	5.2	0.16
425°C	0	3	8.45	1461	71	751	10953	135	101	771	12.1	3.4	4.2	0.13
425°C	50	0	6.76	615	82	468	6362	106	620	50	22.3	1.1	19.9	0.45
425°C	50	1	7.13	1146	86	533	7285	109	611	237	31.7	1.2	14.5	0.67
425°C	50	3	7.83	1880	75	636	9651	106	558	757	46.4	2.6	17.3	0.52
550°C	0	0	7.33	150	77	778	9796	165	104	56	7.7	2.7	1.3	0.03
550°C	0	1	9.19	1049	36	779	11570	201	107	357	11.5	3.0	0.5	0.04
550°C	0	3	8.70	596	53	747	11168	181	97	133	11.1	4.1	0.8	0.04
550°C	50	0	8.30	1109	63	514	8476	149	630	50	25.1	1.8	9.7	0.33
550°C	50	1	8.12	897	53	590	11211	181	617	132	11.5	0.8	3.2	0.17
550°C	50	3	9.33	1098	30	654	11566	200	707	376	20.9	1.5	5.1	0.31
SM	50	0	8.23	171	15	128	3389	91	84	19	1.1	0.2	1.6	0.07
SM	50	1	7.33	191	20	174	3964	93	63	154	4.1	1.2	7.0	0.24
SM	50	3	7.42	478	19	183	4079	97	67	488	3.6	0.4	5.0	0.18

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Table 6: Treatment effects on Amarillo soil properties following TD, oil, and salt treatments. Type I sum of squares. P value included for effects at or very near $\alpha = 0.1$. Interactive effects considered significant only if all simple effects in the interaction are significant at or very near $\alpha = 0.1$. + and - signs next to p-values for single effects indicated whether the treatment effect positively or negatively influences parameter

ANOVA Model Amarillo Soil	Temp	Oil	Salt	Temp x Oil	Temp x Salt	Oil x Salt	Temp x Oil x Salt
Soil Parameter	p-value	p-value	p-value	p-value	p-value	p-value	p-value
pH	0.0133+	0.0035-	0.0117-	0.0013	0.1036	-	-
EC	-	-	0.0001+	-	-	-	-
P	0.0278+	-	-	-	-	-	-
K	<0.0001+	0.0005-	0.0717+	0.0983	-	-	-
Ca	<0.0001+	0.0038-	0.0106-	0.0083	-	-	-
Mg	-	0.0005-	-	-	-	-	-
S	<0.0001+	<0.0001-	-	<0.0001	-	-	-
Na	0.0062+	-	<0.0001+	-	0.0030	-	-
Fe	0.0189+	0.0309-	-	-	-	-	-
Zn	0.0591+	<0.0001-	0.0007+	-	-	-	-
Mn	-	0.0917+	-	-	-	-	-
Cu	-	-	-	-	-	-	-

Table 7: Soil fertility analysis for Billings soil as affected by thermal treatment with and without oil addition at 50 g kg^{-1} by mass, and with and without addition of salt solutions at 1 and 3 ms cm^{-1}. SM = smolder treatment.

Billings Soil - Post Thermal Treatment Soil Fertility

Thermal Treatment	Oil	Salt	pH	EC	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
	g kg^{-1}	mS cm^{-1}		μS cm^{-1}	mg kg^{-1}									
65°C	0	0	7.99	1401	9	191	5871	810	1314	698	3.9	0.2	2.0	0.37
65°C	0	1	8.10	3430	10	183	7214	696	1202	952	2.9	0.2	1.9	0.35
65°C	0	3	8.10	3545	11	214	7979	758	1379	1870	2.7	0.3	2.3	0.44
300°C	0	0	7.73	2481	27	254	5715	658	1522	671	8.4	1.8	4.9	0.64
300°C	0	1	7.79	3417	24	238	5491	618	1398	881	11.4	3.0	8.2	0.87
300°C	0	3	7.88	3202	26	266	5407	651	1220	1708	15.3	4.4	13.4	1.38
300°C	50	0	6.88	721	9	65	1952	248	505	231	2.0	0.1	4.0	0.13
300°C	50	1	6.82	1303	6	23	1114	130	218	129	2.9	0.2	4.5	0.15
300°C	50	3	7.13	1672	11	82	2353	279	580	780	4.4	0.4	6.0	0.23
425°C	0	0	7.96	1543	29	455	4466	526	683	489	11.1	2.6	2.0	0.28
425°C	0	1	8.26	2131	29	464	4098	507	546	712	13.8	3.8	2.2	0.29
425°C	0	3	8.73	2970	31	528	4277	612	401	1323	14.6	3.9	2.0	0.26
425°C	50	0	7.33	663	20	224	3513	292	723	299	10.8	0.5	6.8	0.20
425°C	50	1	7.49	1539	26	267	4296	334	803	527	15.2	0.7	6.4	0.20
425°C	50	3	7.90	2760	21	193	3615	312	528	779	17.7	0.9	6.2	0.22
550°C	0	0	9.52	1140	33	561	4094	1407	402	236	12.2	1.0	1.1	0.09
550°C	0	1	9.79	1316	26	552	4229	2770	336	293	14.3	0.8	1.4	0.06
550°C	0	3	9.96	2385	23	541	5919	3815	277	463	17.4	0.8	1.6	0.07
550°C	50	0	9.32	1045	33	371	3662	1015	656	184	23.4	0.8	8.7	0.46
550°C	50	1	9.62	1333	31	437	3858	2630	553	293	33.0	1.1	7.9	0.41
550°C	50	3	9.68	1744	25	449	4447	3168	512	540	41.5	1.4	9.2	0.42
SM	50	0	7.43	249	6	41	1376	196	327	123	1.4	0.0	2.0	0.11
SM	50	1	7.06	511	9	67	1694	233	467	261	3.6	0.2	3.5	0.15
SM	50	3	7.66	2040	14	169	3685	409	795	927	6.0	0.4	5.0	0.21

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Table 8: Treatment effects on Billings soil properties following TD, oil, and salt treatments. Type I sum of squares. P value included for effects at or very near α = 0.1 Interactive effects considered significant only if all simple effects in the interaction are significant at or very near α = 0.1. + and - signs next to p-values for single effects indicated whether the treatment effect positively or negatively influences parameter

ANOVA Model Billings soil	Temp	Oil	Salt	Temp x Oil	Temp x Salt	Oil x Salt	Temp x Oil x Salt
Soil Parameter	p-value	p-value	p-value	p-value	p-value	p-value	p-value
pH	0.0004^{+}	0.0056^{-}	-	0.0039	-	-	-
EC	0.0184^{-}	0.0222^{-}	0.0342^{+}	-	-	-	-
P	$<0.0001^{+}$	0.0027^{-}	-	0.0131	-	-	-
K	$<0.0001^{+}$	$<0.0001^{-}$	-	0.0079	-	-	-
Ca	0.0014^{-}	$<0.0001^{-}$	-	0.0002	-	-	-
Mg	0.0095^{+}	-	-	-	-	-	-
S	0.0003^{-}	-	-	-	-	-	-
Na	$<0.0001^{+}$	0.0032^{-}	$<0.0001^{+}$	0.0591	0.0127	-	-
Fe	$<0.0001^{+}$	0.0467^{-}	0.0003^{-}	<0.0001	0.0079	-	-
Zn	-	0.0320^{-}	-	-	-	-	-
Mn	-	0.0642^{-}	-	-	-	-	-
Cu	-	-	-	-	-	-	-

Table 9: Soil fertility analysis for Kettleman soil as affected by thermal treatment with and without oil addition at 50 g kg^{-1} by mass, and with and without addition of salt solutions at 1 and 3 ms cm^{-1}. SM = smolder treatment

Kettleman Soil - Post Thermal Treatment Soil Fertility

Thermal Treatment	Oil g kg^{-1}	Salt mS cm^{-1}	pH	EC $\mu S\ cm^{-1}$	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
					---------------------------- mg kg^{-1} -------------------------------									
65°C	0	0	7.93	341	25	468	6259	921	55	390	3.1	0.2	3.9	0.38
65°C	0	1	7.73	305	26	473	6416	935	59	714	1.1	0.2	7.0	0.38
65°C	0	3	7.66	753	29	494	6408	890	54	1391	1.0	0.5	8.3	0.41
300°C	0	0	7.42	497	49	677	6681	687	109	374	24.3	0.7	18.3	0.53
300°C	0	1	7.32	1203	45	627	6483	662	97	650	18.3	0.7	25.3	0.64
300°C	0	3	7.43	1915	47	628	6461	601	98	1152	22.2	1.0	37.2	0.88
300°C	50	0	6.80	438	20	162	2875	244	58	129	2.4	0.0	5.6	0.21
300°C	50	1	6.95	535	22	217	3320	274	63	275	3.8	0.0	8.8	0.32
300°C	50	3	6.73	651	31	320	4260	313	101	704	6.0	0.1	11.5	0.40
425°C	0	0	6.95	490	52	858	5281	356	254	202	34.9	1.3	11.5	0.58
425°C	0	1	7.22	709	52	826	5947	413	223	406	31.2	1.2	19.5	0.54
425°C	0	3	7.42	1462	52	903	5787	359	240	785	28.4	1.8	18.6	0.46
425°C	50	0	6.76	1581	58	653	4945	237	525	200	36.0	0.4	37.5	1.00
425°C	50	1	7.08	844	59	619	4874	204	455	315	23.8	0.3	29.5	0.68
425°C	50	3	7.16	824	61	712	4991	220	448	643	32.6	0.5	35.2	1.11
550°C	0	0	7.12	788	57	902	4085	252	292	127	12.6	0.9	8.6	0.34
550°C	0	1	7.72	600	62	910	4582	256	295	190	14.8	1.4	5.3	0.26
550°C	0	3	8.85	1371	60	990	5192	272	304	336	11.0	0.8	5.3	0.35
550°C	50	0	7.38	776	61	733	4300	240	585	134	24.0	0.5	33.0	1.13
550°C	50	1	7.55	989	54	678	4165	234	617	201	24.7	0.6	26.5	1.11
550°C	50	3	8.26	2070	54	753	4661	249	633	362	20.5	0.5	20.0	1.11
SM	50	0	7.10	232	19	139	2521	260	46	102	4.0	0.0	6.1	0.29
SM	50	1	6.73	1046	30	401	4041	410	235	307	7.2	0.1	7.8	0.24
SM	50	3	6.68	2104	51	966	6185	541	617	867	26.7	0.9	24.4	0.83

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Table 10: Treatment effects on Kettleman soil properties following TD, oil, and salt treatments. Type I sum of squares. P value included for effects at or very near $\alpha = 0.1$ Interactive effects considered significant only if all simple effects in the interaction are significant at or very near $\alpha = 0.1$. + and - signs next to p-values for single effects indicated whether the treatment effect positively or negatively influences parameter

ANOVA Model Kettleman soil	Temp	Oil	Salt	Temp x Oil	Temp x Salt	Oil x Salt	Temp x Oil x Salt
Soil Parameter	p-value	p-value	p-value	p-value	p-value	p-value	p-value
pH	0.0456^-	0.0141^-	0.0248^-	0.0675	0.0133	-	-
EC	0.0344^+	-	0.0081^+	-	-	-	-
P	$<0.0001^+$	0.0883^-	-	0.0575	-	-	-
K	$<0.0001^+$	$<0.0001^-$	-	0.0078	-	-	-
Ca	0.0021^-	0.0004^-	-	0.0082	-	-	-
Mg	$<0.0001^-$	$<0.0001^-$	-	<0.0001	-	-	-
S	$<0.0001^+$	0.0004^-	-	<0.0001	-	-	-
Na	$<0.0001^-$	0.0077^-	$<0.0001^+$	0.0497	0.0001	-	-
Fe	0.0229^+	-	-	-	-	-	-
Zn	0.0078^+	0.0001^-	-	-	-	-	-
Mn	-	-	-	-	-	-	-
Cu	0.0113^-	0.0114^-	-	0.0003	-	-	-

Table 11: Soil fertility analysis for Penwell soil as affected by thermal treatment with and without oil addition at 50 g kg^{-1} by mass, and with and without addition of salt solutions at 1 and 3 ms cm^{-1}. SM = smolder treatment

Penwell Soil - Post Thermal Treatment Soil Fertility

Thermal Treatment	Oil g kg^{-1}	Salt mS cm^{-1}	pH	EC µS cm^{-1}	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
					-------------	-------------	-------------	-------------	mg kg^{-1}	-------------	-------------	-------------	-------------	-------------
65°C	0	0	8.06	76	5	47	456	53	2	3	1.5	0.1	1.6	0.05
65°C	0	1	8.10	340	5	58	449	57	2	283	1.1	0.1	2.2	0.06
65°C	0	3	7.96	784	5	66	459	56	2	896	1.2	0.1	2.3	0.07
300°C	0	0	7.98	42	11	66	468	56	6	23	3.4	0.1	1.9	0.06
300°C	0	1	7.73	545	10	62	530	51	4	226	2.3	0.3	3.4	0.13
300°C	0	3	8.06	2215	11	78	437	48	5	861	3.6	0.4	3.9	0.11
300°C	50	0	5.82	28	1	3	53	8	1	1	0.1	0.0	0.4	0.01
300°C	50	1	7.12	333	1	7	102	9	2	51	0.2	0.0	0.3	0.01
300°C	50	3	6.39	454	1	7	82	9	3	205	0.8	0.0	1.1	0.02
425°C	0	0	7.66	60	12	81	342	47	5	12	3.2	0.1	0.4	0.02
425°C	0	1	7.99	366	13	112	457	48	6	226	3.3	0.4	0.6	0.03
425°C	0	3	8.42	3070	15	147	594	56	10	869	3.6	0.4	0.5	0.03
425°C	50	0	6.62	55	2	10	149	13	16	1	0.6	0.0	0.6	0.01
425°C	50	1	6.39	166	6	38	183	21	124	120	1.0	0.0	0.9	0.01
425°C	50	3	6.98	865	5	46	461	22	186	588	1.1	0.1	0.9	0.01
550°C	0	0	7.35	64	13	106	300	54	6	14	3.0	0.1	0.2	0.01
550°C	0	1	7.59	274	14	136	508	68	10	123	1.6	0.1	0.1	0.01
550°C	0	3	8.22	876	14	178	515	59	15	515	2.0	0.4	0.1	0.01
550°C	50	0	6.33	711	15	145	479	107	307	26	11.0	0.3	8.6	0.02
550°C	50	1	6.66	908	15	130	460	90	301	111	3.5	0.4	4.1	0.02
550°C	50	3	6.66	701	15	150	493	78	400	389	3.8	0.8	4.0	0.02
SM	50	0	6.40	59	1	8	100	14	6	2	0.5	0.0	1.0	0.01
SM	50	1	6.72	212	1	7	92	13	4	82	0.4	0.0	0.7	0.02
SM	50	3	6.43	228	1	9	97	11	10	132	1.1	0.0	0.9	0.02

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Table 12: Treatment effects on Penwell soil properties following TD, oil, and salt treatments. Type I sum of squares. P value included for effects at or very near α = 0.1. Interactive effects considered significant only if all simple effects in the interaction are significant at or very near α = 0.1. + and - signs next to p-values for single effects indicated whether the treatment effect positively or negatively influences parameter

ANOVA Model Penwell soil	Temp	Oil	Salt	Temp x Oil	Temp x Salt	Oil x Salt	Temp x Oil x Salt
Soil Parameter	p-value	p-value	p-value	p-value	p-value	p-value	p-value
pH	0.0026^{-}	<0.0001^{-}	0.0079^{-}	-	-	-	-
EC	-	-	0.0015^{+}	-	-	-	-
P	<0.0001^{+}	<0.0001^{-}	-	0.0013	-	-	-
K	<0.0001^{+}	<0.0001^{-}	0.0211^{+}	0.0005	-	-	-
Ca	-	<0.0001^{-}	0.0150^{-}	-	-	-	-
Mg	0.0186^{+}	0.0062^{-}	-	<0.0001	-	-	-
S	<0.0001^{+}	<0.0001^{-}	0.0380^{-}	<0.0001	-	0.0546	-
Na	0.0321^{-}	0.0034^{-}	<0.0001^{+}	0.0764	0.0423	0.0048	-
Fe	<0.0265^{+}	-	-	-	-	-	-
Zn	0.0096^{-}	-	0.0027^{+}	-	0.0052	-	-
Mn	-	-	-	-	-	-	-
Cu	0.0099^{-}	0.0463^{-}	-	-	-	-	-

Table 13: Changes in nutrient concentrations from post-thermal desorption values in Amarillo soil following 5 week rapid weathering incubation

Amarillo Soil - Nutrient Changes Following Rapid Weathering Incubations

Thermal Treatment	Oil mg kg^{-1}	Salt mS cm^{-1}	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
			Δ mg kg^{-1}									
65°C	0	0	4	20	-475	-37	7	-6	0.2	0.5	15.7	0.17
65°C	0	1	4	32	-538	-40	6	-140	-0.5	0.3	13.6	0.09
65°C	0	3	3	-5	-88	-23	5	-338	-0.5	1.0	14.5	0.02
300°C	0	0	1	122	-159	-2	-22	-4	-3.9	-0.2	5.7	-0.22
300°C	0	1	-4	148	-443	-3	-13	-73	-6.3	-0.2	1.0	-0.21
300°C	0	3	-11	-39	-705	-13	-25	-331	-6.2	-1.6	-5.3	-0.33
300°C	50	0	30	305	2078	77	24	20	-0.4	0.9	4.4	0.39
300°C	50	1	19	200	930	52	16	23	-3.4	0.6	-1.7	0.23
300°C	50	3	4	45	-230	26	-53	-167	-10.7	0.2	-5.9	-0.01
425°C	0	0	5	84	765	-8	-8	-2	-5.4	-0.9	0.8	-0.10
425°C	0	1	-4	80	698	-16	-17	-10	-10.3	-1.2	-2.3	0.01
425°C	0	3	-9	-47	3265	-10	-10	-49	-10.5	-2.3	-2.8	-0.07
425°C	50	0	-7	250	946	14	-171	0	-18.1	-0.5	-13.6	-0.22
425°C	50	1	-20	-14	-325	-1	-297	-68	-25.7	-0.5	-7.9	-0.37
425°C	50	3	-12	-96	-543	-8	-178	-266	-39.0	-1.3	-11.6	-0.22
550°C	0	0	-17	76	1138	15	-21	-2	-5.0	-2.0	-0.8	-0.01
550°C	0	1	-5	144	2626	-40	-21	-20	-9.5	-2.1	-0.3	-0.02
550°C	0	3	-16	109	4080	-4	-10	38	-9.0	-3.3	-0.6	-0.02
550°C	50	0	-21	134	3810	20	-173	6	-19.4	-1.2	-7.1	-0.17
550°C	50	1	-21	91	3838	-3	-93	18	-4.9	-0.1	-0.7	0.01
550°C	50	3	-3	12	1357	-30	-133	-10	-14.6	-0.7	-3.4	-0.17
SM	50	0	23	236	2604	112	80	48	1.4	1.5	13.0	0.38
SM	50	1	18	173	1861	88	46	126	-1.3	1.5	8.9	0.26
SM	50	3	22	180	1815	83	52	322	-1.0	4.1	10.9	0.23

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Table 14: Changes in nutrient concentrations from post-thermal desorption values in Billings soil following 6 week rapid weathering incubation

Billings Soil - Nutrient Changes Following Rapid Weathering Incubations

Thermal Treatment	Oil mg kg^{-1}	Salt mS cm^{-1}	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
			----------------				Δ mg kg^{-1}					----------------
65°C	0	0	2	-13	-180	-165	-260	-296	-2.9	-0.1	0.2	-0.22
65°C	0	1	2	9	-906	-70	-175	-380	-2.0	-0.1	-0.4	-0.22
65°C	0	3	1	-3	-1590	-79	-229	-748	-1.8	-0.2	-0.9	-0.29
300°C	0	0	-8	-43	-344	-121	-490	-314	-6.8	-0.6	3.3	-0.23
300°C	0	1	-5	-22	-213	-54	-132	-343	-10.6	-2.6	-5.2	-0.68
300°C	0	3	-5	-46	-239	-92	119	-644	-14.5	-3.5	-9.6	-1.05
300°C	50	0	4	54	3173	134	319	-2	-1.6	0.0	-2.0	-0.04
300°C	50	1	7	109	4308	268	689	270	-2.6	-0.1	-2.2	-0.04
300°C	50	3	1	39	1731	95	158	-209	-4.0	-0.2	-3.8	-0.13
425°C	0	0	-3	-69	926	-19	862	-96	-9.5	-1.8	-0.9	-0.09
425°C	0	1	-3	-65	919	-10	852	-118	-13.0	-3.4	-1.8	-0.20
425°C	0	3	-5	-134	253	-106	593	-350	-13.8	-3.4	-1.6	-0.18
425°C	50	0	9	70	1616	99	794	-78	-9.3	-0.3	-2.6	0.03
425°C	50	1	3	22	988	58	673	-159	-12.9	-0.3	-1.7	0.05
425°C	50	3	7	98	1619	134	805	-79	-14.7	-0.3	-1.8	0.04
550°C	0	0	-9	113	5664	-274	1102	8	-10.6	-0.9	-0.9	-0.07
550°C	0	1	-4	183	8756	-619	1138	97	-13.2	-0.7	-1.3	-0.05
550°C	0	3	-2	345	11964	-718	1391	287	-16.3	-0.8	-1.5	-0.05
550°C	50	0	-6	111	2092	-151	1030	-17	-20.3	-0.7	-7.3	-0.28
550°C	50	1	10	107	4601	-723	1418	-21	-30.0	-1.0	-7.2	-0.31
550°C	50	3	-8	151	9618	-822	1281	-138	-38.1	-1.3	-8.5	-0.34
SM	50	0	5	61	3660	242	638	196	-0.2	0.2	6.4	0.14
SM	50	1	6	120	4016	339	1132	463	-1.5	0.3	4.9	0.14
SM	50	3	6	71	1686	199	793	385	-3.5	0.2	2.3	0.09

Table 15: Changes in nutrient concentrations from post-thermal desorption values in Kettleman soil following 6 week rapid weathering incubation

Kettleman Soil - Nutrient Changes Following Rapid Weathering Incubations

Thermal Treatment	Oil mg kg^{-1}	Salt mS cm^{-1}	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
				----------------				Δ mg kg^{-1}			----------------	
65°C	0	0	6	13	-438	-45	12	-88	-0.8	0.3	57.8	1.32
65°C	0	1	4	-13	-488	-99	-2	-227	0.8	0.1	46.8	0.95
65°C	0	3	1	3	-780	-79	2	-443	1.3	-0.2	50.2	1.11
300°C	0	0	-8	-60	-806	-13	-20	-75	-22.7	-0.4	16.5	-0.03
300°C	0	1	1	3	-398	-9	-5	-203	-20.6	-0.6	3.1	-0.25
300°C	0	3	15	287	2300	307	42	148	-2.1	0.1	19.5	1.08
300°C	50	0	-6	-45	-530	-20	-20	-164	-16.3	-0.3	14.2	-0.02
300°C	50	1	15	315	2584	338	55	122	-0.7	0.2	24.0	0.97
300°C	50	3	7	171	1041	185	-11	-23	-4.2	0.1	15.5	0.96
425°C	0	0	-6	122	1298	59	-8	52	-33.4	-1.1	-5.1	-0.40

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425°C	0	1	1	74	649	27	-28	80	-26.7	-1.5	-13.2	-0.30
425°C	0	3	-11	179	1109	109	81	48	-21.1	-0.2	-15.7	0.59
425°C	50	0	-8	77	556	31	-30	45	-29.7	-1.0	-8.2	-0.36
425°C	50	1	-15	128	699	104	-4	0	-33.3	-0.4	-19.9	0.32
425°C	50	3	-12	100	680	65	3	-8	-29.8	-0.4	-20.6	0.34
550°C	0	0	-13	170	1526	154	29	2	-11.1	-0.8	-7.6	-0.29
550°C	0	1	2	199	1764	15	91	59	-9.4	-0.6	-4.7	-0.30
550°C	0	3	-5	176	1359	86	42	-2	-22.1	-0.5	-19.0	-0.64
550°C	50	0	-15	185	1954	105	59	24	-13.1	-1.2	-4.7	-0.21
550°C	50	1	-18	79	751	72	-9	-21	-20.0	-0.5	-23.4	-0.47
550°C	50	3	-3	149	1047	26	9	-38	-18.0	-0.4	-14.1	-0.69
SM	50	0	13	370	3526	480	89	208	0.7	0.2	22.5	0.61
SM	50	1	7	287	2226	284	140	157	-1.5	0.1	16.3	0.46
SM	50	3	-6	-72	548	71	-20	-51	-20.3	-0.3	-6.9	-0.23

Table 16: Changes in nutrient concentrations from post-thermal desorption values in Penwell soil following 6 week rapid weathering incubation

Penwell Soil - Nutrient Changes Following Rapid Weathering Incubations

Thermal Treatment	Oil mg kg^{-1}	Salt mS cm^{-1}	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
			----	----	----	----	----	Δ mg kg^{-1}	----	----	----	----
65°C	0	0	8	24	151	5	2	10	-0.8	-0.1	-0.9	-0.01
65°C	0	1	7	21	178	-2	2	-97	-0.6	0.0	-1.3	-0.02
65°C	0	3	2	22	102	-1	2	-214	-0.7	-0.1	-1.1	-0.03
300°C	0	0	6	18	232	6	3	-2	-2.5	0.0	-1.2	-0.04
300°C	0	1	2	19	104	-1	2	-342	-3.1	-0.2	-3.0	-0.07
300°C	0	3	1	13	176	7	14	28	-0.1	0.0	0.0	0.01
300°C	50	0	7	29	31	1	2	-29	-1.7	0.0	-2.4	-0.08
300°C	50	1	1	14	169	10	22	3	-0.1	0.0	-0.1	0.01
300°C	50	3	1	11	180	6	11	-128	-0.8	0.0	-0.9	0.00
425°C	0	0	7	38	213	6	3	4	-2.3	0.0	-0.2	0.00
425°C	0	1	2	15	117	-1	5	-178	-3.0	-0.3	-0.4	0.03
425°C	0	3	5	39	176	5	8	-8	-0.6	0.0	-0.2	0.01
425°C	50	0	10	52	209	3	2	-31	-2.5	-0.3	-0.5	0.00
425°C	50	1	6	58	323	14	67	8	-0.4	0.0	-0.3	0.01
425°C	50	3	7	81	461	13	77	131	-0.6	0.0	0.2	0.01
550°C	0	0	14	87	229	20	3	7	-1.9	-0.1	-0.2	0.01
550°C	0	1	4	32	94	1	9	-107	-1.5	-0.3	-0.1	0.01
550°C	0	3	5	33	90	-2	10	-16	-2.6	-0.3	-2.5	0.01
550°C	50	0	12	59	161	8	8	4	-1.0	-0.1	-0.1	0.01
550°C	50	1	5	36	164	-1	14	-8	-9.7	-0.2	-6.2	0.00
550°C	50	3	5	59	63	6	1	-38	-2.9	-0.6	-2.1	0.00
SM	50	0	2	25	209	26	49	19	-0.1	0.0	-0.3	0.00
SM	50	1	0	16	101	11	26	45	-0.1	0.0	-0.4	-0.01
SM	50	3	3	53	327	25	72	421	-0.4	0.0	0.2	0.00

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Figure 1: Image of smolder apparatus employed in study. Left image shows exterior with temperature probes in use. Right image shows interior of smolder chamber

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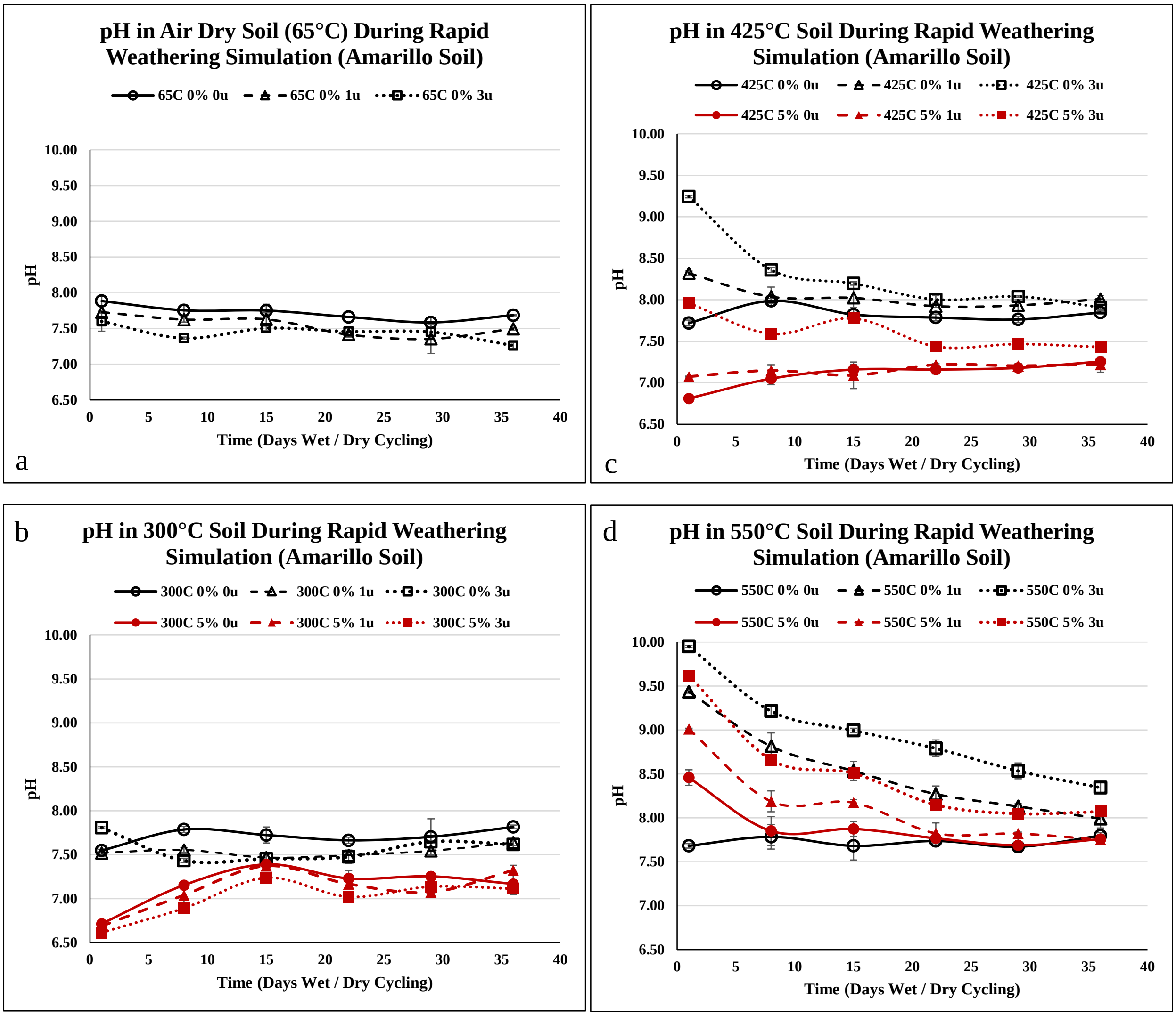

Figure 2a-2d: Soil pH changes over six weeks in Amarillo soil during rapid weathering simulation study. a = soil treated to 65°C at 3 levels of salt addition (0, 1, and 3 µS cm^{-1}). b = TD treated soil at 300°C at 3 levels of salt addition. c = TD treated soil at 425°C at 3 levels of salt addition. d = TD treated soil at 550°C at 3 levels of salt addition. Error bars = 1 standard deviation

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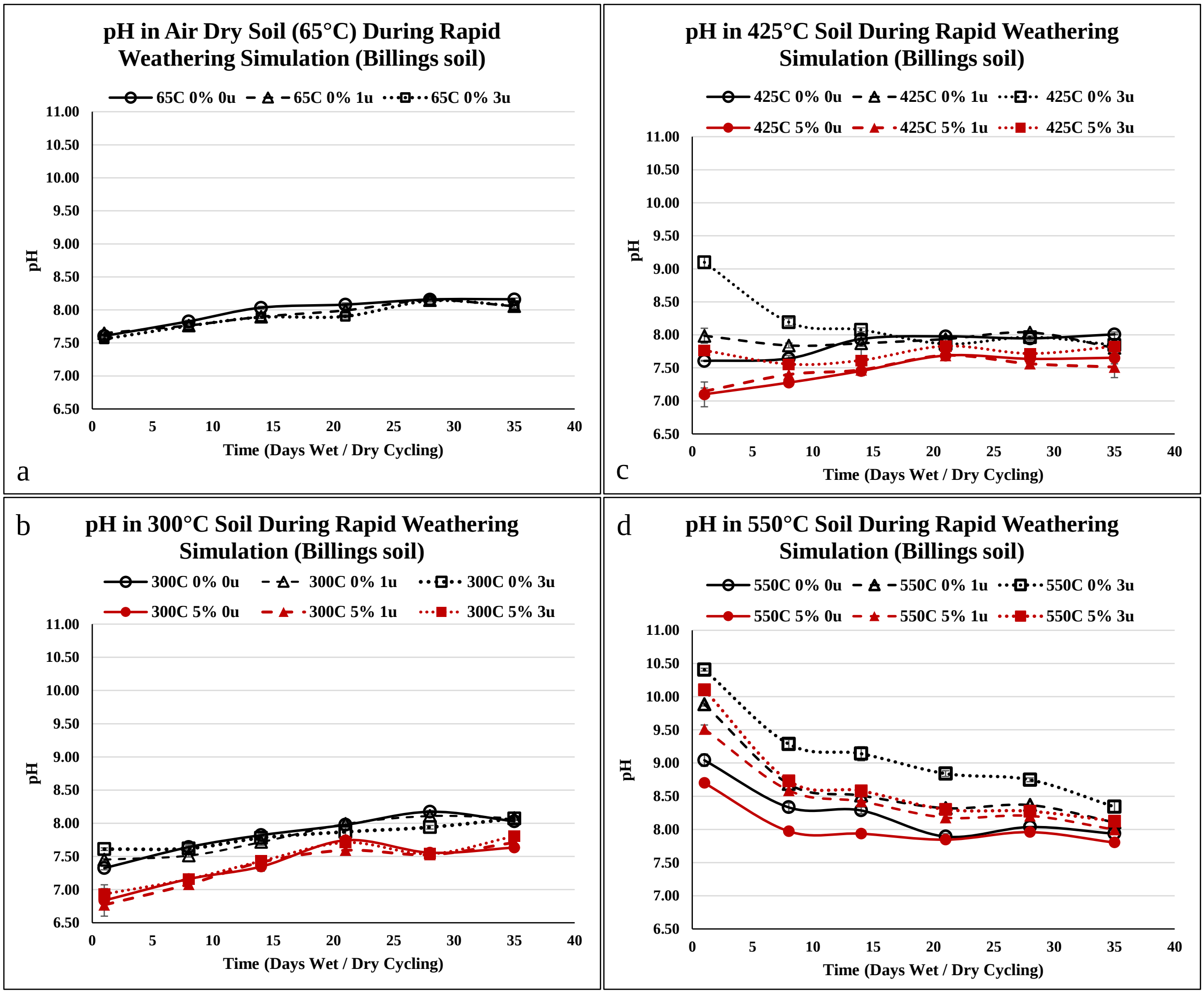

Figure 3a-3d: Soil pH changes over six weeks in Billings soil during rapid weathering simulation study. a = soil treated to 65°C at 3 levels of salt addition (0, 1, and 3 µS cm^{-1}). b = TD treated soil at 300°C at 3 levels of salt addition. c = TD treated soil at 425°C at 3 levels of salt addition. d = TD treated soil at 550°C at 3 levels of salt addition. Error bars = 1 standard deviation

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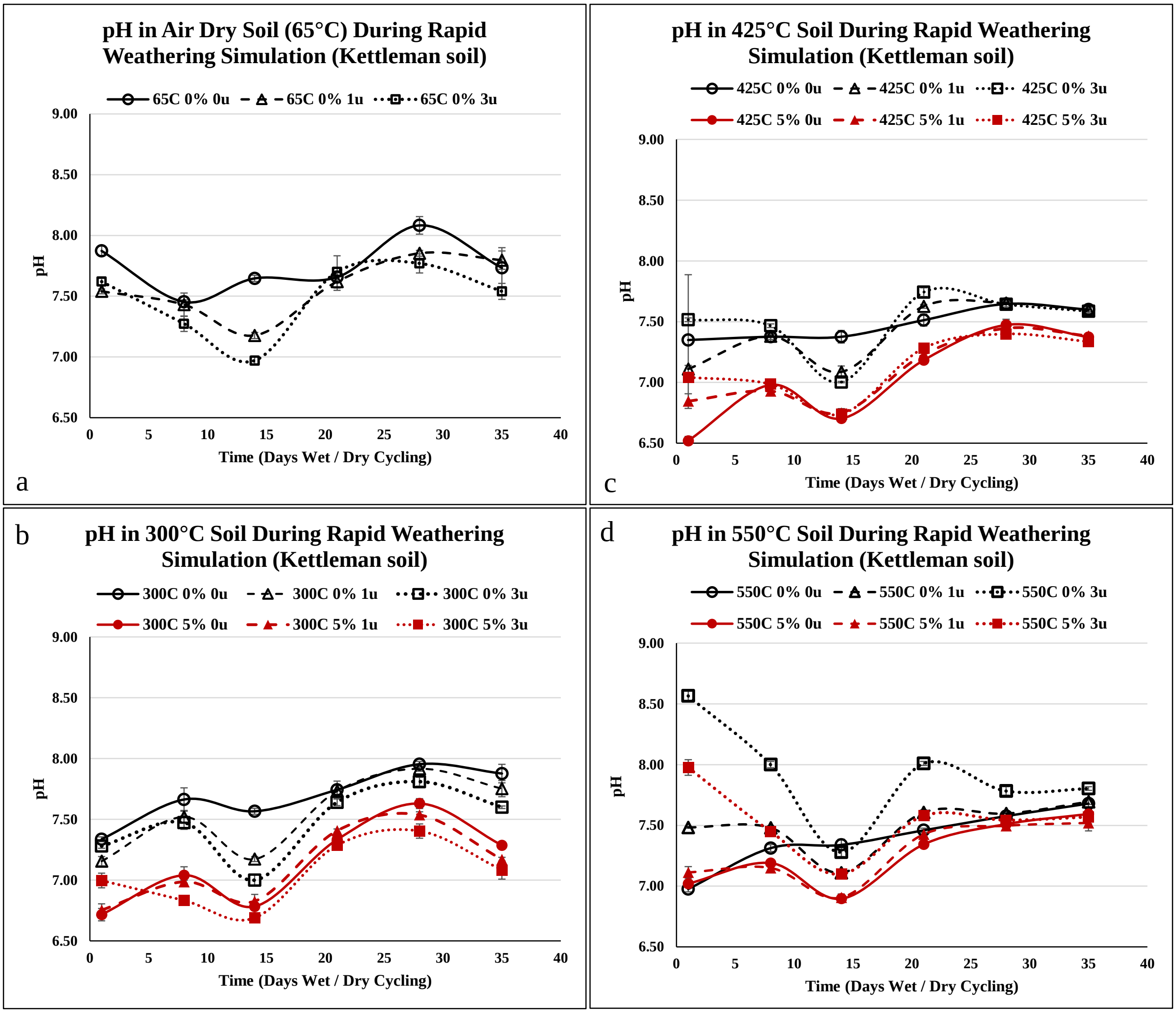

Figure 4a-4d: Soil pH changes over six weeks in Kettleman soil during rapid weathering simulation study. a = soil treated to 65°C at 3 levels of salt addition (0, 1, and 3 µS cm^{-1}). b = TD treated soil at 300°C at 3 levels of salt addition. c = TD treated soil at 425°C at 3 levels of salt addition. d = TD treated soil at 550°C at 3 levels of salt addition. Error bars = 1 standard deviation

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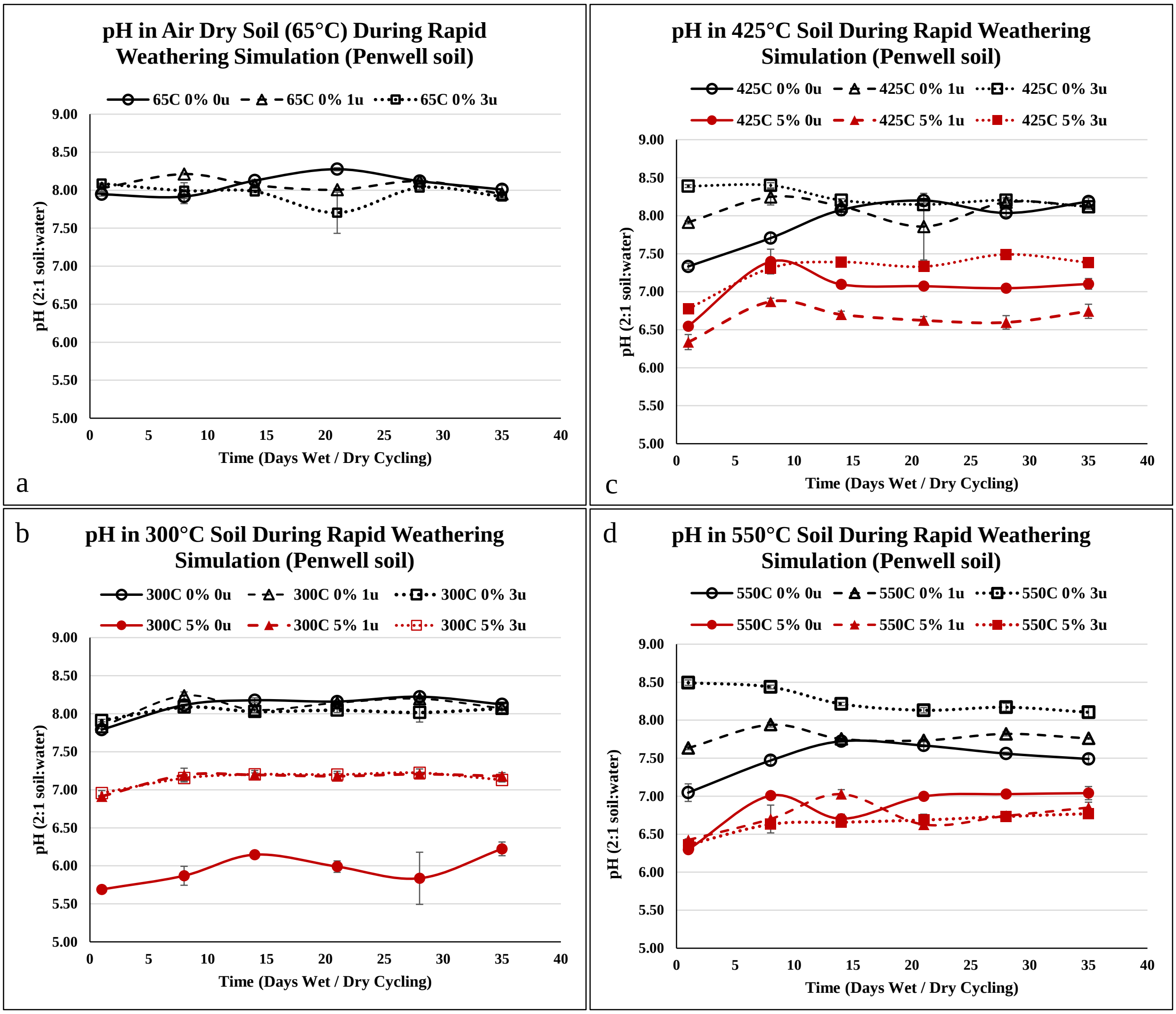

Figure 5a-5d: Soil pH changes over six weeks in Penwell soil during rapid weathering simulation study. a = soil treated to 65°C at 3 levels of salt addition (0, 1, and 3 µS cm^{-1}). b = TD treated soil at 300°C at 3 levels of salt addition. c = TD treated soil at 425°C at 3 levels of salt addition. d = TD treated soil at 550°C at 3 levels of salt addition. Error bars = 1 standard deviation

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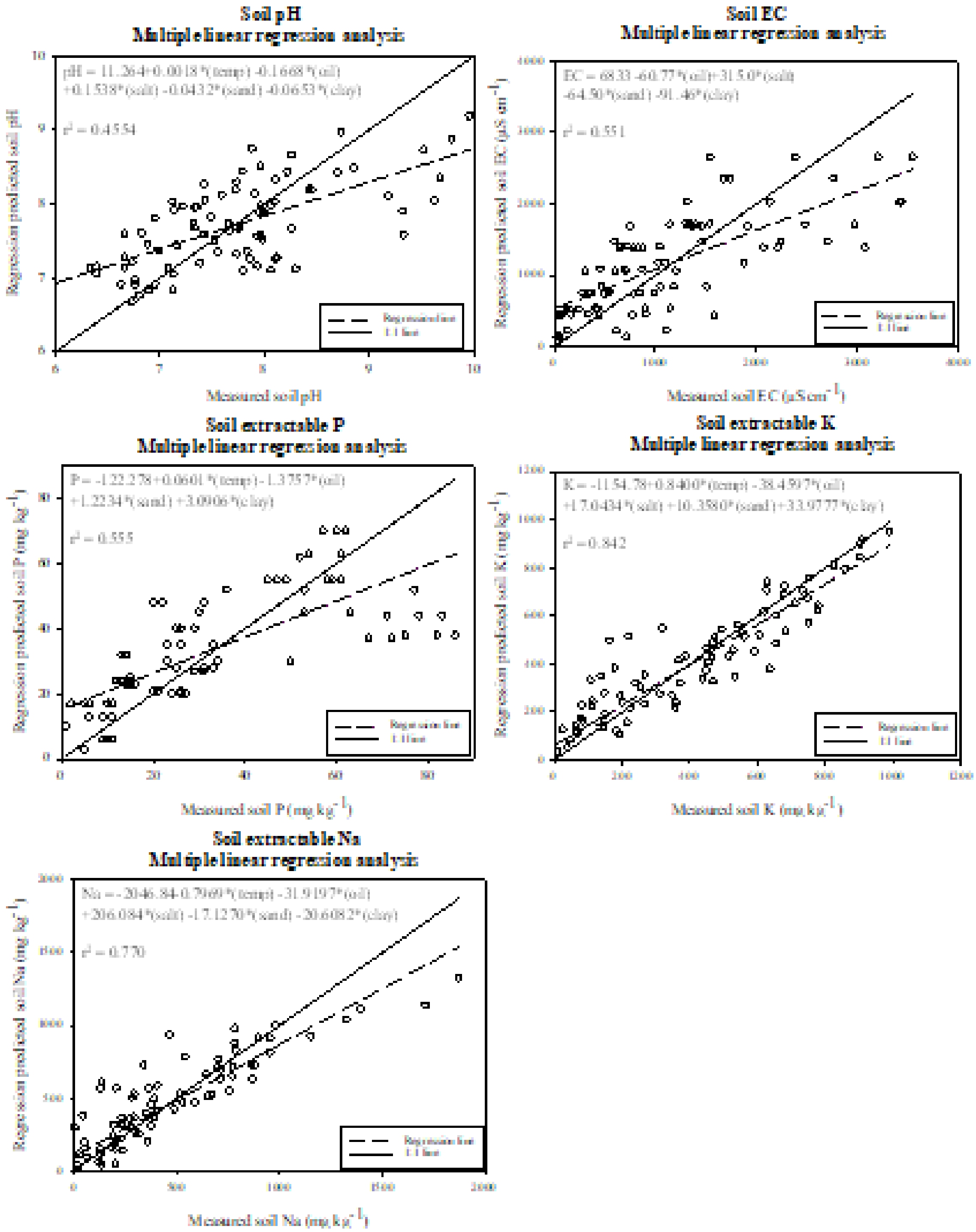

Figure 6: Multiple linear regression analysis results for changes in soil pH, EC, phosphorus (P), potassium (K), and sodium (Na) as a function of temperature of thermal treatment (temp), % sand, % clay, oil addition (oil), and salt addition (salt)

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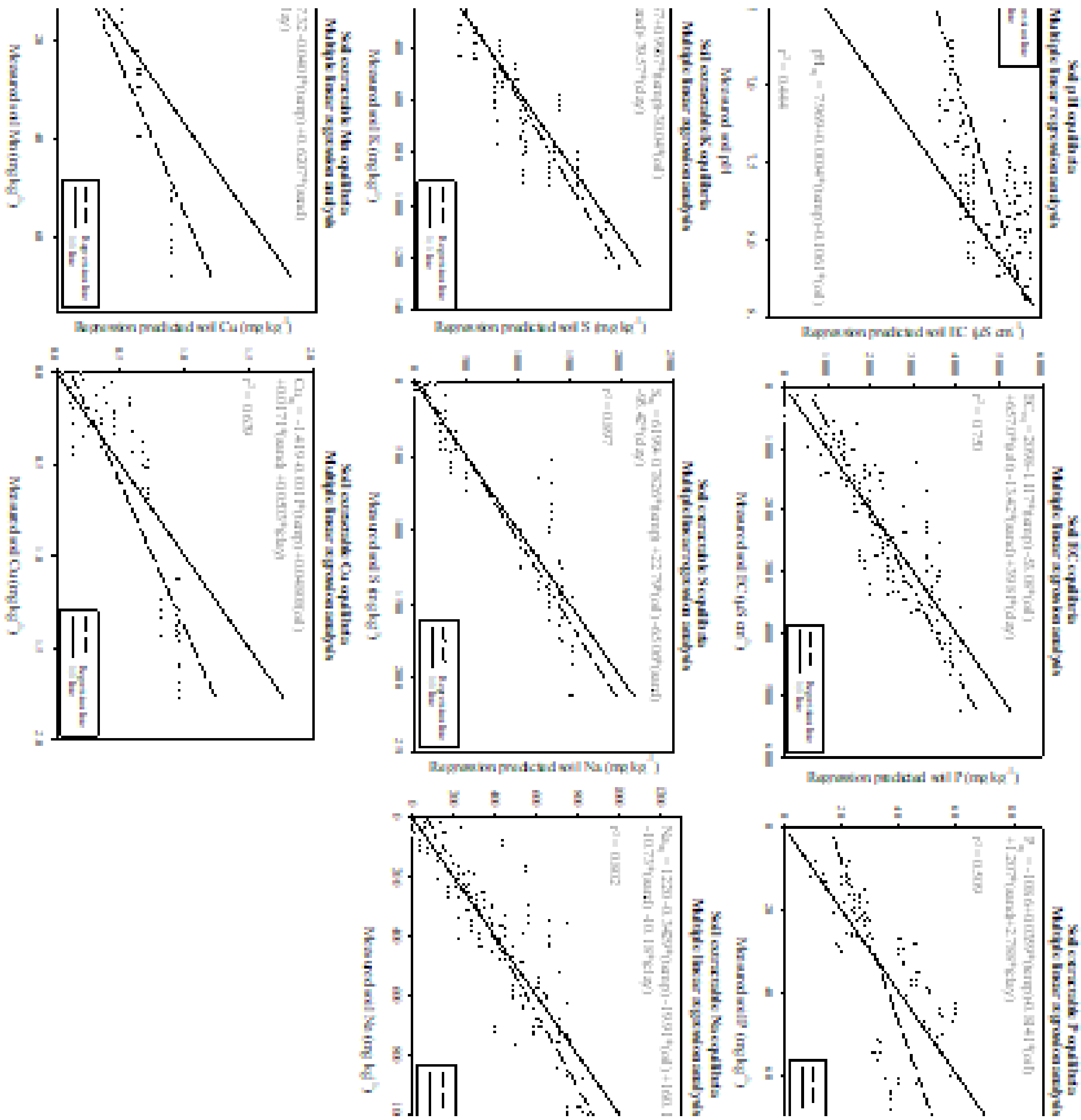

Figure 7: Multiple linear regression analysis results for post-incubation stabilized changes in soil pH, EC, phosphorus (P), potassium (K), sulfur (S), sodium (Na), manganese (Mn), and copper (Cu) as a function of temperature of thermal treatment (temp), % sand, % clay, oil addition (oil), and salt addition (salt)

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Causes of the Earth's Expansion

By Andrzej Pawuła

Abstract- The article answers the question about the cause of the expansion of the Earth. The direct cause of the expansion of the Earth is the increase of basalt magma in the mantle of the globe and oceanic plates. The final answer is short, but it still requires the basic processes and laws of nature to be taken into account. Such a basic issue is explaining the issue of the existence of a heat source in the middle of the Earth and the processes of ionization and recombination of matter. The author argues with the view of the generally accepted theory of lithospheric plate tectonics that there is basically no heat source and the existing endogenous heat of the Earth is relict heat. It is also under dispute that the cause of geological activity is the drift of lithospheric plates.

Keywords: *geothermal energy, earth expansion, basalt magma, thermonuclear georeactor, plasma, recombinetion.*

GJSFR-H Classification: *DDC Code: 508.8 LCC Code: QH11*

CAUSESOFTHEEARTHSEXPANSION

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Causes of the Earth's Expansion

Andrzej Pawuła

Abstract- The article answers the question about the cause of the expansion of the Earth. The direct cause of the expansion of the Earth is the increase of basalt magma in the mantle of the globe and oceanic plates. The final answer is short, but it still requires the basic processes and laws of nature to be taken into account. Such a basic issue is explaining the issue of the existence of a heat source in the middle of the Earth and the processes of ionization and recombination of matter. The author argues with the view of the generally accepted theory of lithospheric plate tectonics that there is basically no heat source and the existing endogenous heat of the Earth is relict heat. It is also under dispute that the cause of geological activity is the drift of lithospheric plates.

According to the theory of the primal forces of nature, the source of endogenous heat is a thermonuclear reactor in the core of the Earth, analogous to a reactor operating in the core of the sun. The peculiarity of the expansion phenomenon is the process of hot plasma recombination. The phenomenon of the expansion of the Earth is related to ionization processes and reactions of the synthesis of ionized particles of matter. Basalt magma is created in the process of recombination of hot plasma, matter with an ionic structure and very high density. The forming basalt magma is a matter with an atomic structure and a density much lower than that of plasma. When an electron is placed in orbit, the particle diameter increases one hundred thousand times. When the plasma pressure exceeds the sealing forces of the reaction chamber, plasma bursts into the D "zone (2,750 - 2,900 km), outside the Earth's core. The phenomenon is analogous to solar prominences. A small volume of plasma ejected with an ionic structure corresponds to a huge volume of basalt with an atomic structure. As a result, the spurt of a small amount of plasma causes a significant increase in the volume of magmatic matter in the center of the globe. Since the electrons involved in the transformation have a low mass, it can be said that the transformation of plasma into basalt magma occurs without changing the mass.

The expansion of the Earth, manifested by a tenfold increase in the volume of the globe, is a phenomenon that appeared 500 million years ago. The new matter is only basalt magma (oceanite). The processes of matter transformation and the action of electromagnetic forces that cause the uplift of the Earth's mantle and the formation of rifts are explained. An important element of the expansion phenomenon is the role of hydrogen, which accounts for over 90% of the magma formed. Under deep conditions, in hot magma, hydrogen initially occurs as a component of the magma alloy and causes the primary expansion effect. At a lower temperature (400-600 ºC), hydrogen is released from the magma as a gas and reacts with elemental carbon to form methane and with carbon monoxide to form methane and water. In this way, the total water resources on the globe and natural gas resources are increasing. The excess hydrogen gas migrates to the atmosphere and accumulates in the exoster.

The cause-and-effect analysis of geological phenomena confirms the thesis about ion synthesis reactions in the Earth's core and the process of hot plasma recombination. So the source of heat is the core of the Earth. and its energy potential tends to increase. You can also refer to geothermal energy as natural nuclear energy.

The explanation of the phenomenon of expansion and the nature of the Earth's endogenous heat source leads to the conclusion about the use of geothermal energy in planning energy and climate policy. Understanding the nature of geological processes clearly indicates the continuity of climate warming and an increase in geological activity. An optimistic conclusion is the prospect of using geothermal energy. In light of this conclusion, the concept of a 10 km deep "heat pump", a deep-sea CHP plant with a capacity of 30-40 MW, becomes particularly interesting. The guarantee of obtaining a positive effect in every place and neutrality for the environment will be strong arguments of the implementation offer.

Keywords: geothermal energy, earth expansion, basalt magma, thermonuclear georeactor, plasma, recombine-tion.

Author: Member of the Polish Geological Society, Poznań, Poland.
e-mail: pawula@amu.edu.pl

I. Introduction

Despite advances in understanding the world, the structure of the Earth's core is still a subject of research and discussion. The traditional geotectonic theory is the Goldschmidt hypothesis of a metallic nucleus, an intermediate sulfide zone, and a silicate mantle. There is a difference of views on the nature of geological phenomena and the evolution of the Earth. This applies to issues such as the Earth's heat source, the rock cycle, and the expansion of the Earth. A supplement to Goldschmidt's theory is the rock cycle, assuming the origin of basalt magma from the remelting of existing rocks. Regarding the structure of the Zemi nucleus, it is believed that the inner part of the nucleus is made of an alloy of iron and nickel, with an admixture of lighter elements: oxygen, sulfur, potassium and carbon (Żelaźniewicz & Grad, 2009). According to the prevailing views, basalt magma is formed from the remelting of old rocks and the cause of volcanism is continental drift. The phenomenon of lithospheric plate subduction and the transport of rock matter in convective cells are suggested. However, the existence of a heat source in the Earth's core is excluded and the hypothesis of "relict heat" is introduced in its place. The matter is important from the point of view of objectivism in science that despite the obvious argument in the form of the geothermal profile (Fig. 12), the facts are denied and the conclusion is accepted that is contrary to the principles

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of thermodynamics. Such views are expressed in the theory of plate tectonics.

An alternative geotectonic theory that interprets these phenomena differently is the theory of global expansion. The authors of the theory of global expansion that explain the effects of this phenomenon are: S.W. Carey (1958, 1976, 1996) and Hilgenberg (1933, 1974). Among the continuators of the research on the phenomenon of expansion are James Maxlow (1995, 2000, 2018) and Jan Koziar (1980, 1985, 2018). The researchers' attention is focused on tectonic forms of expansion, leaving aside the cause-and-effect analysis of the expansion phenomenon.

The cause of the expansion of the Earth was taken up by Hilgenberg, who asked the rhetorical question: "expansion yes, but with or without an increase in the mass of the Earth?". The question had a deep meaning because it was inspired by Kuhn and Rittmann's [1941] statement about solar matter in the Earth's core. These researchers found that there is no metallic Earth's core, but that the interior of the Earth is filled with undifferentiated solar matter. According to Kuhn and Rittmann, in addition to elements such as silicon, iron and magnesium, hydrogen is present in large amounts in the Earth's core. The author of the article continues his work on the cause of the expansion of the Earth: Pawuła (2000, 2021a, b, c, 2022).

II. Expansion of the Earth - Study of the Phenomenon

The phenomenon of the Earth's expansion is the result of thermonuclear processes taking place in the Earth's core. The creation of a georeactor begins with the production of low-temperature plasma, which generates a magnetic field and creates a magnetic trap of this plasma. A magnetically stiffened insulating layer is created, a cover for the future reactor. After exceeding the critical mass of an aggregate of matter, thermonuclear reactions appear spontaneously. It is a common phenomenon in the Cosmos, but requires deeper reflection and associations. We know that there is a relationship between matter and energy in nature, described by the Einstein equation and termed "mass deficit" in nuclide synthesis reactions. We associate gravity with matter. Gravity depends on the mass of this matter, and at the same time we notice that by exerting pressure we destroy its structure. The importance of the forces related to the structure of matter particles was revealed by studies on the structure of the proton [https://phys.org/news/2018-05-subatomic-particle-mechanical-property-reveals.html]. It has been found that the inside of a proton has a huge pressure, 10 times the pressure inside a neutron star.

The phenomenon of Eart's expansion is associated with the destruction of the structure of the atom in the process of ionization of matter and with the nuclide synthesis reactions, with the dominantparticipation of protons. The enthalpy of the p lasma recombination process decreases and the structure of the protons is not compromised (Fig. 1). As a result of the action of gravity, compressive forces appear, the potential energy of gravitational pressure turns into kinetic energy, into heat. The constant increase in the mass of the globe, incl. by gravitational accretion, it causes a constant increase in temperature and ionization energy. By adding energy to the system, the enthalpy increases.

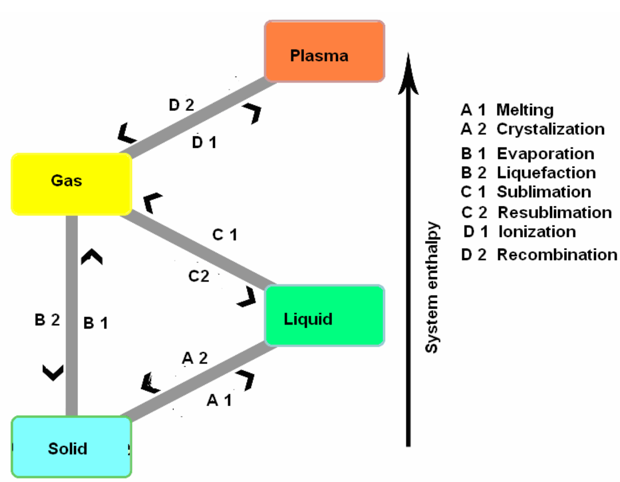

Figure 1: The relationship of energy with the state of matter

Basalt magma is a hot alloy with a temperature of 1150 - 1200°C, a mixture of minerals, liquids and gases, with an elemental composition corresponding to that of the plasma. Basalt magma is created by the recombination of plasma, which gushes out of the Earth's core. The recombination of protons into

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hydrogen atoms is expressed by an increase in the particle diameter 100,000 times. The change in structure causes a sharp increase in pressure and stress in the Earth's mantle. Fissures are formed, reaching the surface of the earth, from which an oceanic spouts. In crevices not reaching the surface, igneous intrusion occurs. Under the deep sea conditions, magma differentiation and crystallization of igneous rocks occur. Plasma, on the other hand, is ionized matter with special electromagnetic properties. Low-temperature plasma is the initial medium that meets the Lawson criterion for the initiation of nuclide synthesis reactions. High-temperature plasma is a product of thermonuclear reactions and constitutes 99% of the mass of the universe.

The phenomenon of the Earth's expansion, expressed in the accelerated growth of the radius of the globe, appeared only when the pressure of hot plasma in the thermonuclear reactor exceeded the gravitational pressure and the magnetic field strength of the reactor's cover. This moment can be defined as 500 million years ago. All the time, in the process of gravitational accretion, the mass and temperature of the globe increased. Structural changes in matter are the effect of the increase in temperature and density of the medium (Fig. 2). In certain critical states of this continuous process, nuclear forces are revealed.

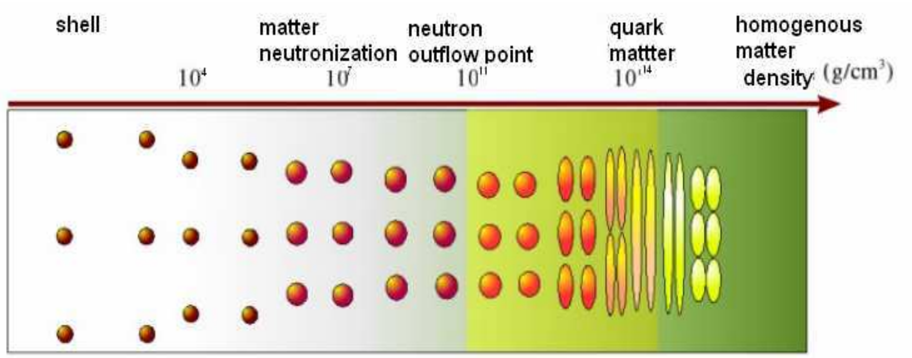

Figure 2: Structural changes of matter as a result of its condensation

Plasma is a good conductor of electric current and, through the eddy currents, it generates a magnetic field and becomes magnetized at the same time. Based on the theory of primal forces of nature, the probability of spontaneous formation of thermonuclear fusion reactors and the determination of the Earth's core as an endogenous heat source has been demonstrated (Pawuła, 2021a).

Hydrogen and its alter ego - proton play a significant role in geological processes.

The main factor facilitating the collision of ions is the formation of a low-temperature layer of liquid plasma as a result of ionization. Liquid plasma has electromagnetic properties, produces a magnetic field and becomes magnetized. The layer of low-temperature plasma forms the shell of the reactor and ensures that the thermonuclear reaction chamber is sealed to the Lawson tightness criterion.

In thermonuclear reactions, hot plasma is created, the components of which are all natural nuclides, with a predominant proportion of protons. In the initial phase of the evolution of the Earth, about 3.8 billion years ago, thermonuclear reactions began, but in a latent form. The appearance of igneous gases creating the primary atmosphere is a confirmation. High-temperature plasma is a product of thermonuclear reactions. The development of this process is illustrated by a comparison of the reactor core densities on Earth (16 g / cm3) and in the Sun (160 g / cm3). Contrary to the idea that the Sun is burning off hydrogen and helium, the theory of the primordial forces of nature treats the evolution of planets as an open sequence that ends with a maximum concentration of matter and a star collapse.

In the universe, hydrogen makes up about 93% of the plasma volume (Figure 3). An explanation of this phenomenon can be found in the following set of equations. Protons, hydrogen nucleons, are excessively formed in heavy ion collision reactions. In the proton-proton hydrogen cycle, apart from positrons, electron neutrinos and gamma rays, nuclear energy is emitted, resulting from the mass transformation (the so-called mass deficit).

$$^{1}H + {}^{1}H \rightarrow {}^{2}H + e^{+} + \nu_e$$

$$^{2}H + {}^{1}H \rightarrow {}^{3}He + \gamma$$

$$^{3}He + {}^{3}He \rightarrow {}^{4}He + {}^{1}H + {}^{1}H + 12{,}86 \cdot 10^{6}\,eV$$

In the collision of two protons, a deuterium nucleus is formed, which in reaction with the next proton produces a helium isotope nucleus. Eventually, the collision of two ^{3}He helium nucleons produces a 4He helium nucleus and two ^{1}H protons. Protons are ejected at high speed, have high kinetic energy and are the

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main source of heat. The emitted energy corresponds to the mass deficit:

- The total mass of the two ^3He helium nuclei is 10.0122E-24 g.
- The total mass of the ^4He nucleus and both protons is 9.98928E-24 g.
- Weight difference 0.0229E-24 g,
- Equivalent energy 12.86E + 6 eV
- The difference in mass is emitted as energy of electromagnetic radiation.

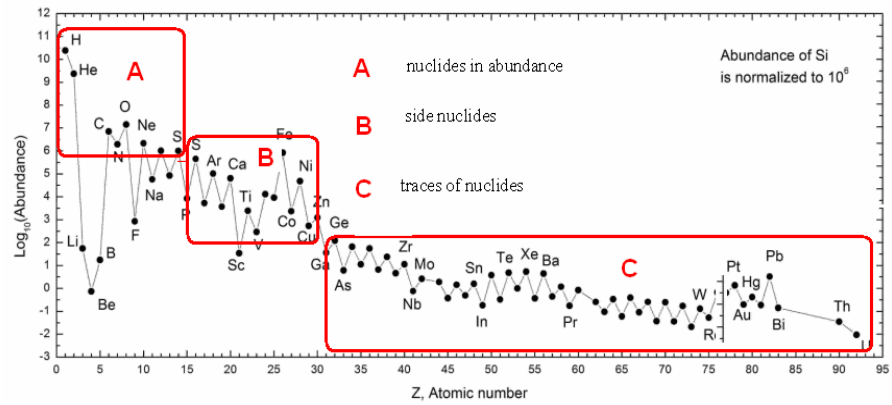

Figure 3: Ion composition of the universe's plasma

The phenomenon of ion collisions, apparently impossible to be induced in terrestrial conditions, in fact appears in space as a common and spontaneous phenomenon. Light nuclides, mainly nuclei of hydrogen and helium atoms, most often take part in the collision reactions.

A characteristic feature of the Earth's expansion process is the increase in the volume of the globe, without any increase in mass. The explanation for this phenomenon is the plasma recombination process, including, in particular, structural changes in proton/ hydrogen. The importance of hydrogen lies in its small size and abundance in hot plasma.

In thermonuclear reactions, hot plasma is created, the components of which are all natural nuclides, with a predominant proportion of protons. The protons are replaced by hydrogen atoms whose diameter is 100,000 times the diameter of the proton. Describing the phenomenon of recombination, we can say that the change in the electric charge of a matter particle caused the volume of this particle to increase so enormously. Proton recombination is the addition of orbital electrons. Chemical elements are formed that react with each other. The protons dominating in the plasma transform into hydrogen, which reacts with elemental carbon and carbon monoxide to form methane and water:

$$2H_2 + C \rightarrow CH_4$$
$$3H_2 + CO \rightarrow CH_4 + H_2O$$

Basalt magma has special properties, it is homogeneous, identical regardless of the age and place of discharge, and its elemental composition is similar to solar plasma. Hot plasma contains a broad spectrum of rare elements and a small but constant amount of uranium and thorium. Basalt magma lacks the light elements, hydrogen, nitrogen and carbon, which dominated the plasma.

Basalt magma, which does not flow out through volcano chimneys and is slowly cooling down, is subject to a differentiation process. Under characteristic temperature conditions, elements and mineral compounds precipitate. In the temperature range of 400 - 600°C, the pneumatolytic stage takes place, when gases are released from the magma (Fig. 7).

Hydrogen plays a special role in the expansion phenomenon. During the transformation from a proton, as a component of an igneous alloy, it increases in volume and causes the uplift of the Earth's mantle. The effect of the uplift is the crevices into which the magma is pressed. Magma intrusion, batolitas and global rifts are formed. The phenomenon of expansion is expressed by the production of basalt magma and an accelerated increase in the volume of the Earth. The growth curve of the radius of the Earth takes the form of an exponential function (Fig. 4).

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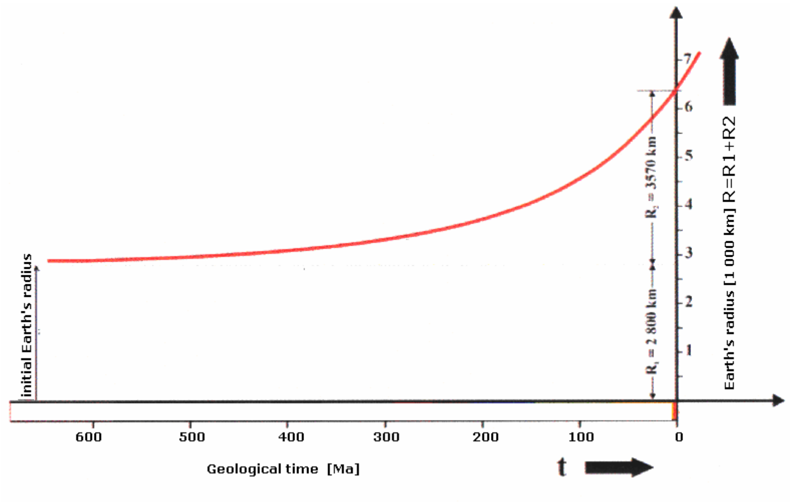

Fig. 4: Earth radius growth curve (Koziar, J., 2018)

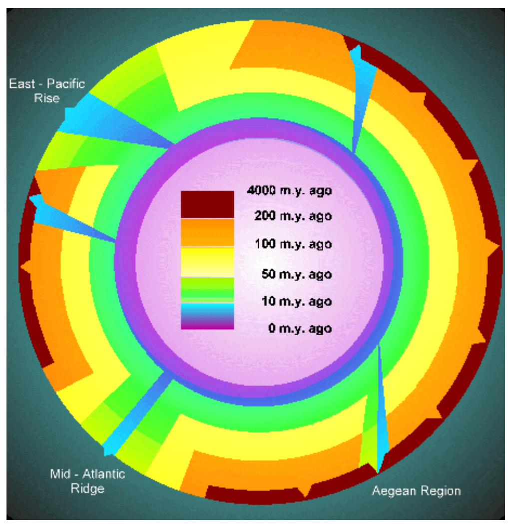

Fig. 5: The ideological model of an expanding Earth /www.nationalgeographic.org/tickets/events/

According to Koziar's (1980) calculations, the contemporary annual increase in the radius of the Earth is 2.6 cm / year. Calculations show that in the last 280 million years the volume of the Earth has increased tenfold without increasing the mass of the globe. There is only a shift of dense matter from the Earth's core to the transformation zone D ". In the expanding Earth model (Fig.5), contemporary matter dated 0 -10 thousand years BP occurs in the D" layer and in the ocean rift zone. Moving away from the rift line and the D "zone, there are older layers, up to the Jurassic.

Volcanic eruption is caused by magma pressure, and under certain conditions, there is also an eruption of igneous gases. This has to do with the mineral composition and temperature of the magma. Primary basalt lava in the exuberant volcanoes of Hawaii has a temperature in the range of 1100 ÷ 1250°C, it is liquid and rich in dark minerals. In explosive volcanoes, lava has a rhyolite mineral composition, it is enriched with silica and has a lower temperature, in the range of 750 ÷ 900 ° C. As a result of temperature drop (<900 ° C), mafic minerals (Mg - Fe) precipitate from the magma and form rhyolite magma enriched with silica. Gases are released, mainly hydrogen, which reacts with carbon, carbon oxides and sulfur to form methane, water and hydrogen sulphide (Fig. 6).

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Nowa Zelandia

Figure 6: Sulfur fumaroles (White Island)

Under certain conditions, the accumulated hydrogen and methane will explode, causing severe earthquakes (explosive volcanoes). Hot magma remaining in zone D "presses on the mantle of the globe, causing magma intrusion and metasomatosis of the rocks encountered. In the temperature range of 400-600°C, the magma degassing process takes place. Due to the fact that hydrogen constitutes 90% of the elemental composition of magma in the recombination process, the degassing effect is felt in the ground as strong seismic shocks.

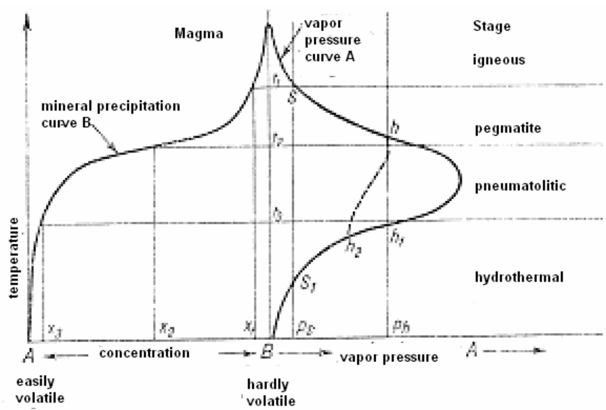

Figure 7: Niggli's post-magmatic stages

The released igneous gases react with each other. The photo shows the source of igneous solutions at 400°C (Fig. 8). The presence of hydrogen gas H_2 and its reaction products with carbon (methane CH_4) and sulfur (H_2S). The mineral compounds of silicon, titanium, aluminum, iron, manganese, calcium, sodium, potassium and phosphorus crystallize in the basalt rock, as well as numerous trace elements: basalt magma is an evident evidence of the existence of a thermonuclear georeactor in the Earth's core. The hydrogen gas reacts violently with carbon to form dry methane and reacts with carbon monoxide to form juvenile water and methane. Under high pressure, methane squeezes through the rocks of the Earth's mantle and explodes during a volcanic eruption.

a temperature of 400 - 600 ºC:

$_2$, H_2, HCl, H_2S, SO_2, CH_4, H_2O, NH_3, P_4O_{10}:

Ocean plates, formed by basalt magma, cover more than 70% of the globe. During 280 million years, the volume of the Earth's globe has increased tenfold: it has increased from 9.2E+10 km3 (Earth's radius R1 = 2800 km), to the present 1.08E+12 km3 (Earth's radius R2 = 6373 km). Thus, there was an increase in the volume of the Earth by 9.88E+11 km3 and this is the volume of basalt magma that was produced in the process of plasma recombination.

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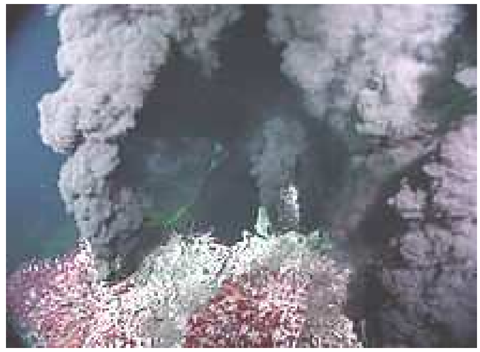

Fig. 8: Black smoker hydrothermal chimney (National Oceanographic Data Center)

The global cross-section shows the proportion of the small Earth globe, before the expansion (outline of continents) and the ten times larger growth zone, created in the process of matter transformation (Fig. 9).

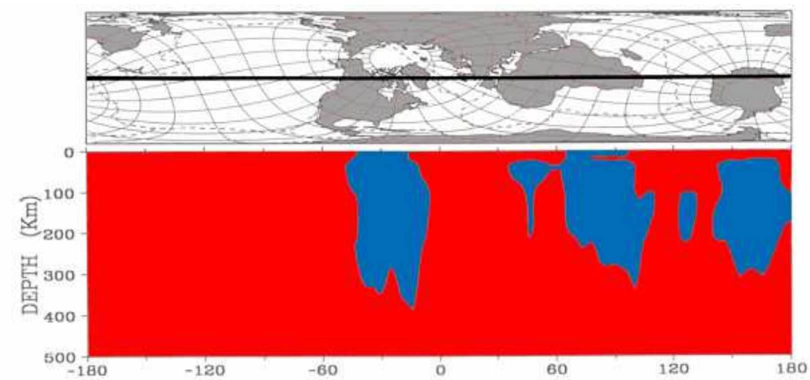

Fig. 9: Global structural section [Zhang, Y.S., Tanimoto, T., 1993]

It can therefore be concluded that during this period the georeactor produced plasma, which formed 9.88E+11 km3 of basalt magma (3.53E+3 km3 / year). If magma is trapped in the Earth's mantle, it will differentiate and degass. As it cools, the hydrogen accumulates in gas traps and reacts with elemental carbon or carbon oxides to form flammable methane and water [1]/.

Volcanic eruptions and earthquakes are then irregular, separated by periods of calm, but violent. Hydrogen which does not react with carbon or carbon monoxide to form methane and water is released into the atmosphere. Since it is over 14 times lighter than air, it escapes to the exosphere (Fig. 10).

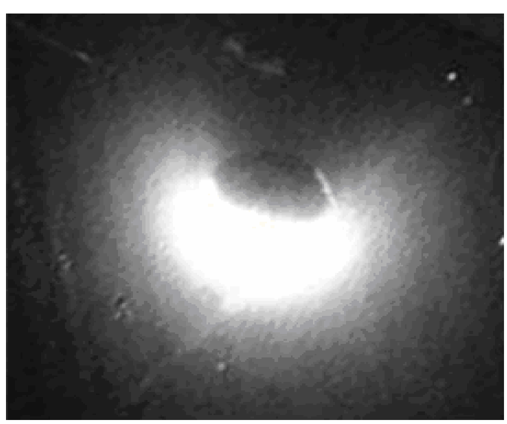

Fig. 10: Hydrogen in the Earth's exosphere (ultraviolet photo)

[1] Regarding that water which is juvenile water and the quantity of which is constantly increasing. In the Precambrian period, juvenile water froze and caused global glaciation. In the Palaeozoic, due to the appearance of the phenomenon of expansion, the climate warmed and the epicontinental seas were created. Fossils of marine organisms on the Himalayan peaks come from this period. Sea regression only occurred in the Tertiary period, 65 million years ago, when ocean basins began to form. Due to the appearance of the phenomenon of expansion and uplift, an orogenic period occurred. According to this interpretation of the Earth evolution scenario, there were no orogeny prior to the Tertiary.

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The photo on the moon was taken by astronaut John Young as part of the Apollo 16 space mission (1972). https://malagabay.wordpress.com/2013/04/11/terrestrial-degasssing-of-hydrogen-and-helium/.

Evidence of the correct interpretation of the Earth's expansion phenomenon is the detection of the missing hydrogen in the Earth's exosphere.

Table 1: Components of volcanic gases (% vol.)

Components	Kilauea (Hawaii)	Nyiragongo (Congo)	Mont Pélé, */ (Martinique)
CO_2	21,4	40,9	10,2
CO	0,8	2,4	2,0
H_2	0,9	0,8	0,2
SO_2	11,5	4,4	
S_2	0,7	-	0,5
SO_3	1,8	-	-
Cl_2	0,1	-	0,4
N + rare gases	10,1	8,3	0,9
H_2O	52,7	43,2	82,5

** / Source: MacDonald G. A., 1972: Volcanoes.Prentice - Hall Inc., New Jerse*

III. Geothermal Energy

The author argues with the view of the generally accepted theory of lithospheric plate tectonics that the endogenous heat of the Earth is the relict heat of the globe and the cause of geological activity is the drift of lithospheric plates. The dispute is about the fundamental issue, the source of heat in the Earth's core, which the theory of plate tectonics does not take into account. According to the theory of the primal forces of nature, the source of endogenous heat is a thermonuclear reactor in the core of the Earth, analogous to a reactor operating in the core of the sun. Evidence of the existence of a heat source in the Earth's core is the geothermal profile (Fig. 11). According to the laws of thermodynamics, the temperature increases as we approach a heat source.

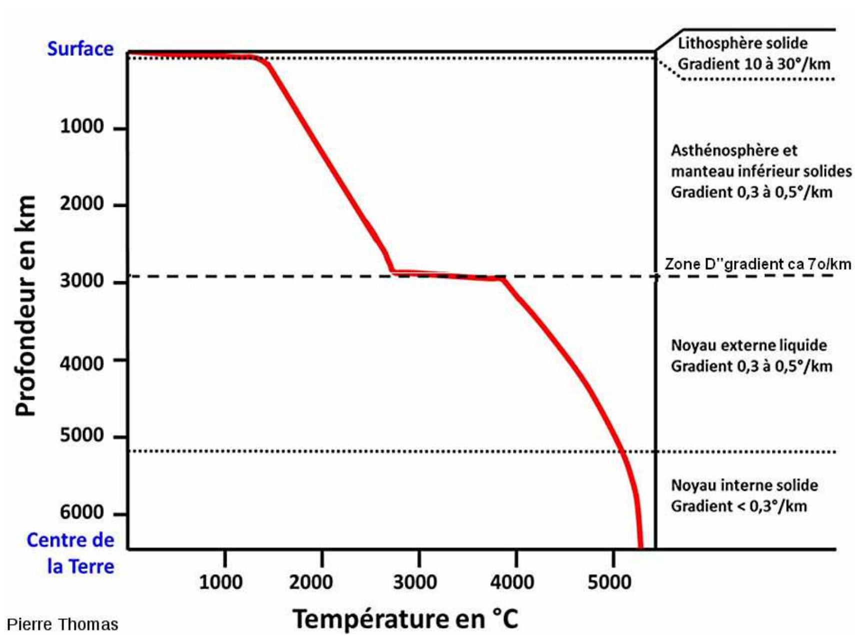

Fig. 11: Geothermal profile of the Earth

[La chaleur de la Terre et la géothermie — Planet-Terre planet-terre.ens-lyon.fr]

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So the source of heat is the core of the Earth. and its energy potential tends to increase. So you can refer to geothermal energy as natural nuclear energy.

The map of the geothermal flux density (Fig. 12) shows the zoning of the activity of geological processes and is a picture of the globe's expansion.

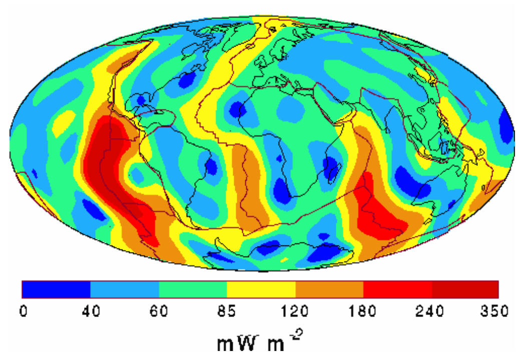

Fig.12: Earth's heat flux density

[Pollack et al., 1993: http://www.geo.lsa.umich.edu/ IHFC/heatflow.htm]

The lowest heat flux densities, below 0.07 W/m2, are found in the area of continental plates. In the rift zone, the heat flux density increases several times, to 0.35 W / m2, and the global thermal power of the Earth is Q = 35 742 448 MW. The map of the geothermal flux density (Fig. 12) shows the zoning of the activity of geological processes and is a picture of the globe's expansion. The fundamental conclusion emerges from the Earth's evolution scenario. Thermal changes are increasing in nature. There is a general trend of climate warming, periods with a downward trend in average temperatures, it occurs incidentally due to factors such as the dustiness of the atmosphere with volcanic ash.

Fig. 13: Sahara. River meanders from the pluvial period (Photo A. Pawuła)

Several thousand years ago, the Sahara was green. The climate was warm and humid. In the area of the present desert, there are deep river valleys (Fig. 13), traces of settlement by people of different cultures and civilizations have been preserved.

At that time, northern Europe was covered with Arctic glacial ice. Over these several thousand years, the climate has warmed significantly. The direction of climate change is obvious, one should recognize the inevitability of these changes. Information about climate warming in Antarctica refer to the same phenomenon, because the phenomenon has a global dimension. The problem of global warming is best presented on the example of Antarctica (Fig. 14).

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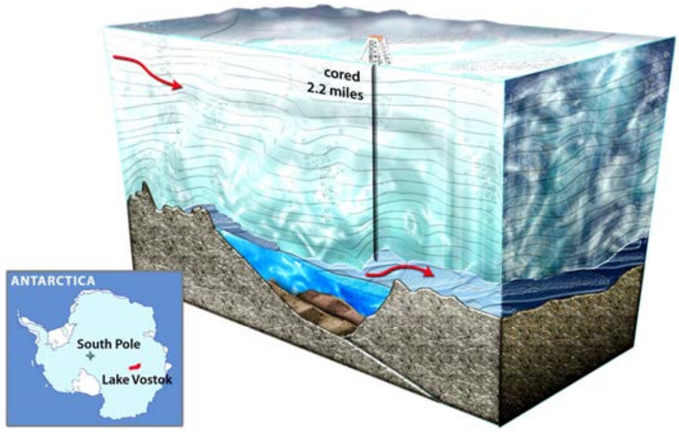

Fig. 14: Lake Vostok under the Antarctic ice sheet (Retejum, 2021)

Geophysical surveys have detected a huge water reservoir under the ice sheet - Lake Vostok. In the research zone, a stream of gases from the deep ground, dominated by hydrogen, was detected. To explain this phenomenon of nature, one should take into account the fact that there are numerous volcanoes under the Antarctic ice. The research report explains the global warming in Antarctica by the degassing of the ground caused by continental drift. (Rejetun, 2021). Such an interpretation of the soil degassing phenomenon under the Antarctic ice sheet is not convincing. Continental drift does not cause processes such as plasma recombination.

Taking into account the accelerated process of the Earth's expansion, one should predict an increase in the geothermal flux density and its increasing influence on climate warming. There are several hundred active volcanoes from which volcanic ashes and gases are discharged, incl. carbon dioxide, hydrogen, hydrogen chloride, sulfur dioxide, hydrogen sulfide, methane, ammonia. The fundamental conclusion emerges from the Earth's evolution scenario. Thermal changes are increasing in nature. There is a general trend of climate warming, periods with a downward trend in average temperatures, it occurs incidentally due to factors such as the dustiness of the atmosphere with volcanic ash.

The picture of climate change in the evolutionary aspect of the theory of the primal forces of nature looks as follows: "In the Precambrian about 3.8 billion years ago, the first geothermal symptoms appeared, emanations of igneous gases, including water vapor. In the absence of an atmosphere, water vapor appeared. It froze, forming first the polar ice sheet, and then the global glaciation. Traces of the Precambrian glaciation, which lasted until the beginning of the Palaeozoic, were preserved in the form of tilites, among others in the Moorish Sahara (Adrar Plateau). Geological activity was present under the ice sheet, as it is now. under the ice of Antarctica. The conclusion is that the Antarctic ice sheet has lasted continuously since the Precambrian. When considering hard coal deposits, Spitzbergen has the answer - carbon deposits were formed from igneous coal with the help of bacteria - methanotrophs. , there is an organic life based on the energy of hydrocarbons (chemosynthesis) s global warming is irreversible!

There are various methods and techniques for managing geothermal energy, by taking hot groundwater or hot reservoir brine, or by injecting water to heat it, or by direct heat extraction. The main differences between individual systems relate to the contact with the environment, through the intake of water or brine, and discharges of sewage. In the case of deep drilling, capturing hot water from crystalline rocks, crushing the rocks and treating them with chemicals is a troublesome procedure.

The choice of the type of intake depends on the resources and energy demand. Designing should take into account the local geological conditions, especially the local geothermal gradient. Geothermal gradient - extreme values: 20°C / km - 40°C / km

The figure (Fig. 15) shows three geothermal systems:

- Low-temperature geothermal energy, also known as "heat pump", uses a heat exchanger similar to domestic refrigerators, but in the reverse order. Thermal energy is recovered by lowering the temperature of the circulating medium. Theoretically, they can extract heat from water or atmospheric air at a temperature close to zero degrees. In this type of installation, the "heaters" are placed at a depth of about 1.5 m.
- The second installation is used for hot water abstraction (balneology) in an area with the above geothermal gradient. Generally, geothermal gradients are in the range of 20-40 °C / km. In the nearsurface zone of the lithosphere, the geothermal gradient is rectilinear. Medium-temperature

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geothermal energy refers to the extraction of heat from hot mineral water or reservoir brine.

- The third hot rock geothermal model concerns forced flow through a crushed crystalline rock. This system, called "deep", is used in the energy sector. The depth of the holes used was 3 km, however, it turned out to be too small. Water with a temperature of 100 degrees Celsius was too low for energy needs. It was decided to go to a depth of 5 km, but the problems of rock crushing, water injection and environmental impact remained.

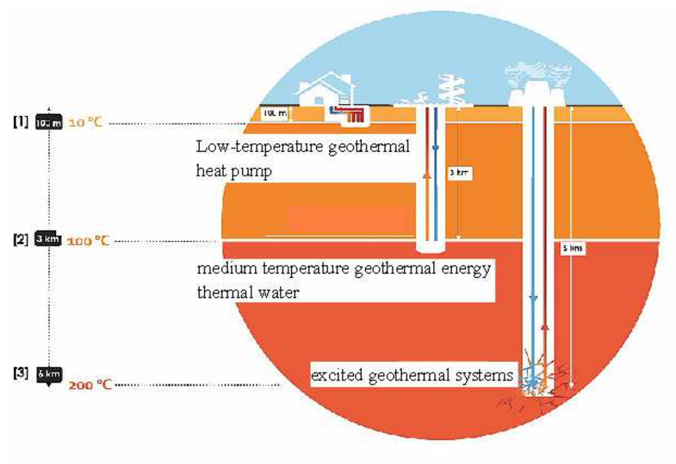

Figure 15: Geothermal systems [Gąsiewicz et al.]

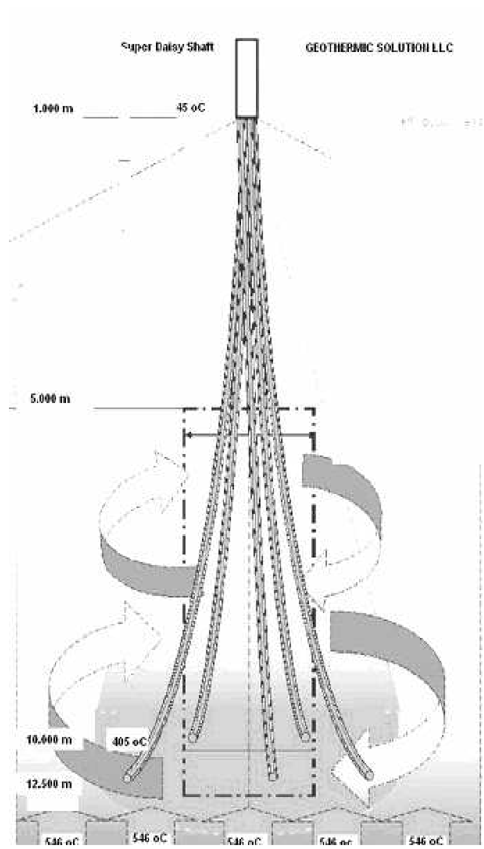

Fig. 16: Deepwater CHP plant 30-40 MW

[source: Consiliari Partners (Bohdan M. Żakiewicz) http://consiliari.pl/geo_plutonic_energy/]

The fourth model is a modified deep model (Fig. 16). The modification consists in eliminating crushing of rocks and chemical preparations and contact with the natural environment. An important detail of the drilling technology is the increase in the depth of the boreholes to more than 10 km and the introduction of a closed circuit of the working fluid. This solution is optimal for the power industry. The first implementations

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of such geothermal installations were successful The geothermal model, called "deep-sea CHP plants" has been tested on several sites (Oklahoma (1979), depth over 10 km; Qatar (2008) depth 12.3 km, implementation time 35 days; Sakhalin (2011), depth 12.3 km, delivery time 60 days). The drilling rigs are adapted to drilling to a depth of 10,000 meters. The heat source is guaranteed in the high depth zone. Based on data obtained from existing deepwater power plants, the cost of kWh of electricity produced is cheaper than any other electricity generation technology currently available.

IV. Conclusions

The most important conclusion concerns geothermal energy and the outlook for its management. The problem of choosing a geothermal installation is related to the determination of the heat source. Proving the thesis that there is an unlimited heat source in the Earth's core gives an argument to promote the concept of building deep-sea CHP plants. The prospect of satisfying the energy needs on a global scale is emerging!

In scientific views, the dispute over truth has its material dimension. Staying with the view that there is no heat source in the middle of the globe is because the thermonuclear georeactor is an alternative view. And such a view is ruled out by physicists, supporters of the Big Bang theory.

In this article, the author explains why the Earth is expanding. In order to comment on this, it is necessary to explain what this phenomenon is and what are the traces of its operation.

The reason for the expansion of the Earth is the increase of basalt magma in the mantle of the globe and oceanic plates. The expansion phenomenon is caused by the operation of a thermonuclear reactor in the Earth's core. The direct cause of the expansion is the eruption of plasma from the Earth's core into zone D". From the point of view of physico-chemical processes, it is the process of plasma recombination into basalt magma.

The expansion began on Earth in an initial (latent) form of 500 million. BP years, and in the developed (explicit) form, BP 280 million years. During this time, the volume of the Earth has increased tenfold. All growth is basalt magma. The globe radius growth curve is an exponential function, which indicates the acceleration of the phenomenon.

The plasma recombination process causes a sharp increase in pressure, the appearance of tectonic stresses, seismic tremors and volcanic eruptions. The resulting elements form basalt magma, the characteristic feature of which is the stability of the chemical composition.

Basalt rock (oceanite) is devoid of hydrogen, which is degassed. The process of plasma recombination causes a rapid increase in pressure, the appearance of tectonic stresses, seismic shocks and volcanic eruptions.

The resulting elements form basalt magma, the characteristic feature of which is the stability of the chemical composition. Basalt magma contains all natural elements, but at the temperature of 400 - 600°C it loses gaseous components, mainly hydrogen. High concentrations of hydrogen have been detected near the Antarctic ice sheet, in the zone of volcanic activity and in the Earth's exosphere.

The management of geothermal energy is a rationally justified direction of exploration. Among the analyzed types of installations, preference is given to heat pumps, low-temperature individual users, and deep-sea CHP plants, 10 km deep and 30-40 MW, for municipal purposes.

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Greenhouse Gases: Background Issues

By José Luis Pinedo-Vega, Fernando Mireles-García, Carlos Ríos-Martínez & Ignacio Dávila-Rangel

Universidad Autónoma de Zacatecas

Abstract- This paper re-discusses the relationship of greenhouse gases (GHG) with fossil energy consumption together with clean and renewable energies. It is shown that GHG has an increasing trend despite the spectacular growth of renewable energies, the promotion of energy savings, and the incorporation of more efficient energy systems; which is indicative that fossil energies grow at a speed superior to clean energies. This explains that natural mechanisms of GHG destruction are not infallible. In particular, it is emphasized that photosynthesis is restricted to CO_2, it can only act at the level of the leaves of plants, therefore it cannot be expected to process the CO_2 from the rest of the atmosphere, and it is impossible for it to act on other GHGs. That means that reforestation, although very valuable, cannot be expected to be an infallible solution. In addition, it is noted that, despite the alleged commitment of almost 200 states present in the COP26 the initiatives remain declarative, are restricted to CO_2, and are still far from being operational, as is the case with the proposals to sequester CO_2. And indeed, there are no concrete initiatives to combat the rest of the GHGs.

Keywords: greenhouse gases, fossil energy consumption, clean energy, renewable energy.

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GREENHOUSEGASESBACKGROUNDISSUES

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Greenhouse Gases: Background Issues

José Luis Pinedo-Vega [α], Fernando Mireles-García [σ], Carlos Ríos-Martínez [ρ] & Ignacio Dávila-Rangel [Ѡ]

Abstract- This paper re-discusses the relationship of greenhouse gases (GHG) with fossil energy consumption together with clean and renewable energies. It is shown that GHG has an increasing trend despite the spectacular growth of renewable energies, the promotion of energy savings, and the incorporation of more efficient energy systems; which is indicative that fossil energies grow at a speed superior to clean energies. This explains that natural mechanisms of GHG destruction are not infallible. In particular, it is emphasized that photosynthesis is restricted to CO_2, it can only act at the level of the leaves of plants, therefore it cannot be expected to process the CO_2 from the rest of the atmosphere, and it is impossible for it to act on other GHGs. That means that reforestation, although very valuable, cannot be expected to be an infallible solution. In addition, it is noted that, despite the alleged commitment of almost 200 states present in the COP26 the initiatives remain declarative, are restricted to CO_2, and are still far from being operational, as is the case with the proposals to sequester CO_2. And indeed, there are no concrete initiatives to combat the rest of the GHGs.

Keywords: greenhouse gases, fossil energy consumption, clean energy, renewable energy.

I. Introduction

Until a few years ago, it was understood that climate changes were potential problems and that their eventual effects would be seen in the long term. Unequivocal evidence of the acceleration of climate changes are: the increase in the number and intensity of hurricanes, with increasingly frequent and more devastating floods; the succession of extreme droughts and heat waves, which often cause forest fires, deforestation, losses in agriculture and livestock; and the melting of the polar ice caps and high mountains glaciers.

Each year, about 80 cyclones and tropical storms are formed around the world. Those with categories 4 and 5 have doubled his number between 1970 and 2010 (*Schweitzer, 2014*). Consequently, the power dissipation index (PDI) of Atlantic storms, which measures the hurricane intensity, has been duplicated since the 1970's (*McLendon, 2017*).

By 2014, one of the consequences hitherto unforeseeable was evident; the greenhouse effect was no longer the only problem. Atmospheric pollution was responsible for about 2 million premature deaths per year in the world due to respiratory problems, caused by PM2.5 particles and combustion gases (*Walther 2014, Garric, 2015*). This warning accelerated the development of clean energy sources, particularly in China, the country with the highest GHG emission rate.

If cleaning tasks on the mainland are difficult, at sea and in the atmosphere, on a large scale, they are practically impossible. Without technology -which does not exist today- and without consuming energy, it is impossible to go down to the ocean's depths to eliminate the myriad of pollutants that have accumulated. It is also impossible to go high to eliminate the atmospheric GHG. *Rohde & Muller* (*2015*), with justified reason, warn that "The atmosphere pollution is the worst ecological catastrophe in the world." The oceans and atmosphere pollution are the greatest ecological disasters happened on Earth after the extinction of the dinosaurs.

Many worldwide actions are combined to claim to stop climate change. Even though the several UN Conferences of Parties (COPs) encouraging the Kyoto Protocol, the infinity of other conferences and events, the underlying problem is that the GHG concentration keeps rising. All this put into question the effectiveness of the set of all the initiatives; or rather, they warned about the fact that, although all the initiatives to preserve the Earth are extremely valuable, they are not enough to prevent climate change.

This document tries to clarify which are the obstacles preventing the fight against climate change from thriving. It will be concluded that the underlying problems have not been correctly visualized, and there are no legal mechanisms to impose solutions. Among other factors, governments do not have the power or will to induce a reduction in both fossil fuel consumption and GHG emissions.

II. Some Precisions about Greenhouse Gases (GHG)

GHGs are all kinds of atmospheric gaseous polyatomic molecules (of more than two atoms), which have the property of trapping a fraction of the infrared radiation (IR) that the Earth should emit into space (*Butler, 2020*). The most crucial GHG are: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), and Chlorofluorocarbons (CFC). Their ability to trap infrared radiation is typified by a factor called Global Warming Potential (GWP). CO_2 has the lowest GWP (GWP = 1) but it is the most abundant one, therefore it contributes the most to global warming. The methane (CH_4) follows in abundance, with a GWP = 25, meaning that each molecule has a reheating power equivalent to 25 molecules of CO_2. Then follows the nitrous oxide (N_2O),

Author α σ ρ Ѡ: Universidad Autónoma de Zacatecas, Department: UAEN, Ciprés 10, Fracc. La Peñuela, Zacatecas.
e-mail: jlpinedo@uaz.edu.mx

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whose GWP= 298. The chlorofluorocarbons, the most giant polyatomic molecules found in the atmosphere, have a GWP between 1800 and 22000 (*Hofmann, 2006*).

Figure 1, published by the National Oceanic and Atmospheric Administration (*NOAA, 2022*), shows the trends, over the last forty years, of the accumulation in the atmosphere of the leading GHG. It can be seen that CO_2 and CH_4 have stationary variations, but not N_2O. For N_2O, it can be easily verified that the growth rate is 0.777 ppb per year, which implies an accumulation of 4.11 million of tons (Mt) of N_2O per year.

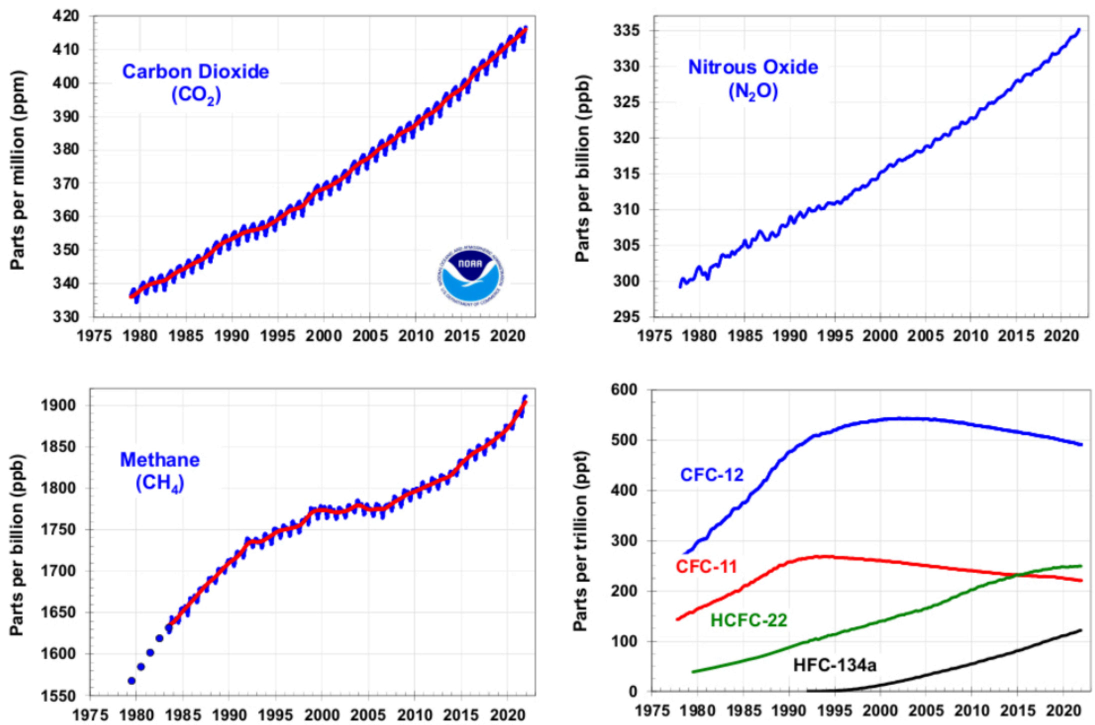

Figure 1: The trend of the main greenhouse gases

Source: http://www.esrl.noaa.gov/gmd/aggi/, [On line 2022]

It can be shown that N_2O with a current concentration of 335 ppb and aGWP = 298, is equivalent to 99.8 ppm of CO_2. This implies that the contribution of N_2O to the heating of the atmosphere is of the order of 24% concerning to CO_2, thing that have not deserved enough importance.

Similarly, it can be verified that CH_4 with a concentration of 1920 ppb and a GWP = 25, is equivalent to 48 ppm of CO_2; that is, its contribution of the order of 11% additional to that of CO_2.

And in the case of CFC-12, with a concentration of 500 ppt and a GWP = 10 900, it is equivalent to 5.45 ppm of CO_2. And the contribution of the remaining CFCs is equivalent to 0.89 ppm of CO_2.

Summarizing, the actual GHG set has a greenhouse effect on the atmosphere equivalent to 572 ppm of CO_2. It means that GHGs have doubled with respect to the pre-industrial era.

The life in the atmosphere of N_2O is 114 years, which implies that the current generation will not be able to see the end of N_2O that it has generated. That is why N_2O should be worrisome.

Figure 2, also published by *NOAA* (*2022*), shows the evolution of the accumulation in the atmosphere of CO_2-Accumulated implies that it could not be destroyed naturally-. A growth rate of 2.4 ppm of CO_2 per year can be observed in the graph. Assuming that the atmosphere's mass is $5.29x10^{18}(kg)$, it can be easily demonstrated that 1 ppm of any component in the atmosphere is equivalent to $5.29x10^{12}(kg)$ or 5290 (Mt). Therefore, if the rate of CO_2 accumulation is 2.4 ppm per year, this implies that 12700 Mt of CO_2 accumulate in the atmosphere year after year.

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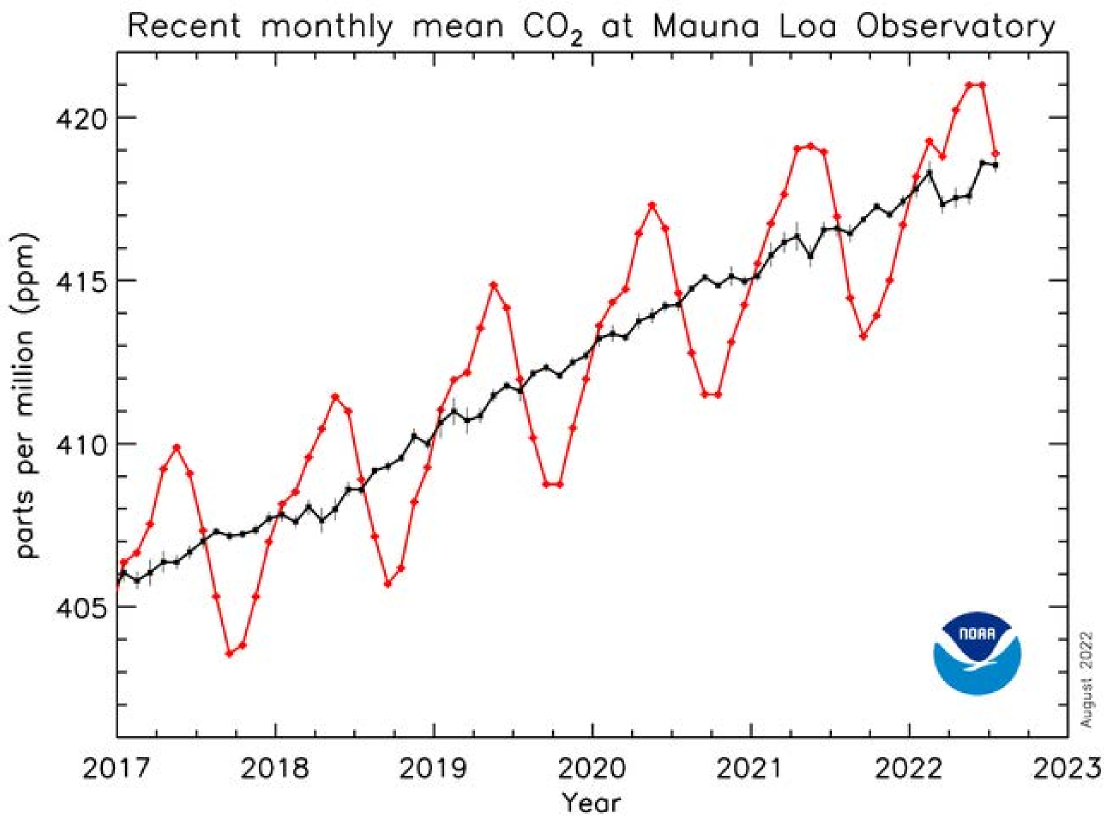

Figure 2: Recent monthly means CO_2 at Mauna Loa

Source: https://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_trend_mlo.png [On line 2022].

But, as if that were not enough, CO_2 not only produces a greenhouse effect. In the Polar atmosphere, where the temperatures are freezing, it condenses and forms stratospheric clouds that serve as a liquid medium that facilitates the destruction of ozone, by the chlorine action of CFCs. CO_2 plays an essential role in the appearance of the ozone hole and continues to influence the destruction of ozone molecules.

There are three mechanisms of natural elimination of CO_2: photosynthesis, dragging through rainwater, and destruction by photo dissociation with UVC radiation.

Vegetation absorbs CO_2, but only the one in the vicinity of the leaves; obviously, plants are not vacuum cleaners. Therefore, they cannot process CO_2 that is far from their reach. So, planting trees and caring for forests are not enough to counteract the accumulation of CO_2 in the atmosphere. In apaper that appeared in *Science*, it was argued that the forest area at that time was 10% higher than the previous assessment (*Le Hir, 2017, Bastin, 2017*). However, it can be seen in Figures 1 and 2, that there has been no decrease in the CO_2 concentration trend. This proves that reforestation is essential, but it is an insufficient action to reduce CO_2 effectively.

Rain can drag a certain amount of CO_2, but only the one below the clouds. But the CO_2 dragged by rainwater is not entirely beneficial since it changes the pH of rivers and seas, causing the gradual extinction of coral, in which the food chain of multiple maritime species begins.

According to the National Oceanic and Atmospheric Administration (*NOAA*), in mid-2022, in the Mauna Loa laboratory, an average concentration of 418 ppm of CO_2 has already been recorded (Figure 1); a concentration that existed at the time of the Pliocene, 2 million years ago. In the last million years, the mean concentration was 280 ppm. This level has increased by 50 % in just two centuries.

Because of its abundance and multiple effects, the first priority is to attack CO_2 in the most efficient way possible.

The IPCC proposes to retain or trap CO_2 before being released into the atmosphere. However, this requires a technology that has not yet been fully developed, which is still in the experimental phase and will be sophisticated and expensive in both financial and energy terms. In calculations, 20% of the energy consumed is required to prevent the release of CO_2 into the atmosphere. Unfortunately, this technology cannot be applied to transport, domestic consumption or small

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industry (*Metz, 2005*). However, capture is restricted for future CO_2, and not for accumulated in the atmosphere; because of this, the only alternative is CO_2 destruction in a natural way.

The natural elimination mechanisms of CO_2 fulfill their function, as they have always done. Unfortunately, these mechanisms - photosynthesis, rain drag, and photo dissociation - do not act for other pollutants since their physical and chemical properties are different. GHG are very stable molecules, with a fort molecular bond energy. With the exception of methane, the rest of the GHG have a long life or remains in the atmosphere for a very long time. Therefore, it is imperative to treat them individually, generating appropriate technology to capture or retain them, rather than releasing them into the atmosphere.

III. World Energy Consumption

According *BP Statistical Review* (*2022*), in 2021, global primary energy consumption reached 595.15 Exa Joule (EJ) or 14 215 million tons of oil equivalent (Mtoe). The total consumption of primary energy grew at a rate of 5.8% in the year. Its average rate in the last 10 years (2011-2021) was 1.3% per year, the fastest since 2010.

Fossil energy accounted for 82.3% of the total - 31.0 % oil, 24.4 % natural gas, and 26.9 % coal. The contribution of clean energy sources was 17.7 % -4.25 % of nuclear energy, 6.75 % of hydroelectricity, and 6.70% of renewable energy-.

Clean energies are considered those energy sources that do not release CO_2 when used; these energy sources are also recognized as carbon-free energy sources. It should be emphasized that not all renewable energy is clean. Of this 6.70%, 50.9% is wind energy, 28.3% is solar energy, and the remaining 20.8% includes biofuels and biomass, which are not clean energies, because they are actually fuels; they produce CO_2 when burned. So, subtracting biofuels, renewable sources only provide 5.3% of CO_2-free energy.

Fuels – oil, coal, natural gas, biofuels, and biomass – supply 83.7% of the energy consumed in the world. Clean or CO_2-free energies - hydraulic, nuclear, wind and solar, together represent only 16.3%.

In 2021 oil consumption grew 5.8%, consumption natural gas increased 5.3%, coal consumption grew 6.3 %, nuclear generation increased 3.8 %, hydroelectric generation decreased 1.8% while renewable energy grew 16.5%.

Since 2007, China has been the world's leading energy consumer. In 2021, China consumed 26.5% of the world's energy, followed by the United States (15.6 %), India (6.0 %), Russia (5.3 %), Japan (3.0 %), Canada (2.3 %), Germany (2.1 %), South Korea (2.1%), Brazil (2.1%), Iran (2.0 %), France (1.6 %), United Kingdom (1.2 %), Indonesia (1.4%) Mexico, Italy and Turkey (1.1%).

The energy sources consumed in greatest proportion are fossil sources –oil, coal, and natural gas - due to their abundance and technological easiness for extraction, refining, and transport; however, all of them produce greenhouse gases (GHG).

World *oil* consumption in 2021 grew by 6.0 %. The United States remains the world's leading oil consumer; consuming 19.9%; It was followed by China (16.4%), India (5.2 %), Saudi Arabia (3.8 %), Japan (3.6 %), Russia (3.6 %), South Korea (3.0 %), Brazil (2.4 %), Canada (2.4 %), Germany (2.2 %), Iran (1.8 %), Indonesia(1.6%), France (1.5 %), Mexico (1.4 %).

Favored by higher hydrogen content, *natural gas* is the fossil fuel with the lowest emissions of CO_2 (651 kg de carbon per ton of natural gas) (*Jancovici, 2006*). Its emissions represent about 60% with respect to coal and 70% with respect to oil.

In 2021, world consumption of natural gas increased by 5.3 %.Their price is very variable globally, being practically three times more expensive in Japan and twice in Europe, compared to the price in the United States. The United States remains the world's major consumer of natural gas. Its consumption represented 20.5 %. It was followed by Russia (11.8 %), China (9.4 %), Iran (6.0 %), Canada (3%), Saudi Arabia (2.9 %), Japan (2.6 %), Mexico (2.2 %).

Coal is the primary energy source that generates GHG in greater proportion (1.2 tons of carbon per ton of oil equivalent (toe) (*Jancovici, 2006*). Favored for being the cheapest source of energy in the world (100-150 US $ /ton) and despite the fact that the price more than doubled in the year, global coal consumption increased by 6.3 % in 2021. China remains the world first coal consumer. In 2021, China's consumption accounted for 53.8 %; followed by India (12.5 %), United States (6.6 %), Japan (3.0%), South Africa (2.2 %), Russian Federation (2.1 %), Indonesia (2.0 %), South Korea (1.9 %), and Germany (1.3%). Asia accounted for 79.9% of global coal consumption, making it the most polluted region on the planet.

IV. Role of Clean Energies

In 2020, *clean energy* consumption was 92.51 EJ and in 2021 was 97.14 EJ; that is, there was a net increase of 4.63EJ, which represented 5.0 %. In 2021, the contribution of clean energy to the world energy supplies was 16.31% - hydroelectricity accounted for 6.76 %, nuclear energy 4.25 %, wind and solar energies 5.30%.

That year (2021), they had a spectacular increase of 17.0 % due to wind power and 22.3 % to solar. However, the increase equals only 4.63 EJ.

In 2020 fossil energy consumption was 463.7 EJ, while in 2021 it was 489.6 EJ. Oil consumption increased by 10 EJ, natural gas by 6.9 EJ, while coal increased by 9 EJ. That is, in 2021, the net increase in

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fossil source energy was 25.9 EJ, equivalent to 5.6 %; 77.2 % of this increase (e.i. 20 EJ) was the responsibility of only 4 countries: China (10 EJ), the United States (4.4 EJ), India (3.2 EJ) and Russia (2.4 EJ).

The net increase in fossil source energy (25.9 EJ) was 5.6 times the net increase of all clean energy (4.63 EJ).

The share of clean energy sources is very important, - they avoid the order of 16.3% of the emissions of CO_2-. But they are far from offsetting the increased concentration of CO_2 in the atmosphere produced by fossil sources.

V. The World Production of CO_2

In 2021, the global release of CO_2 into the atmosphere amounted to 33,884.1 million tons (MT). The emissions of CO_2 worldwide increased by 5.9 %, a figure much higher than the 1% growth observed in the decade (2007-2017). This is undoubtedly due to fossil energy consumption, which increased by 5.6 %.

China is the country that emits the most CO_2 into the atmosphere. In 2021 its emissions amounted to 10,523Mt (31.1 % of the world total); followed by the United States 4,701.3 MT (13.9 %), India 2,552.8 Mt (7.5%), Russia 1,581.3 Mt (4.7%), Japan 1,053.7 Mt (3.1 %), Iran 660.5 Mt (1.9%), Germany 628.9 Mt (1.9 %), South Korea 603.9 Mt (1.8 %), Saudi Arabia 573.5 Mt (1.7%), Canada 527.4 Mt (1.6%), Brazil 436.6 Mt (1.3%), Mexico 373.8 Mt (1.1 %), United Kingdom 337.7 Mt (1.0 %).

China, the United States, and India, produce 52.5 % of the emissions of CO_2. Emissions reach 60.3 % if Russia and Japan are added. The previous 13 countries are responsible for 72.3% of CO_2 emissions. The most polluting industries are: the electricity-mainly because 61 % is produced by fossil sources: 36 % produced by coal, 22.9 % by natural gas, and 2.5 % by oil-; the oil production, the steel industry, the cement companies and of course the transportation.

VI. Pioneers on Renewable Energy

China is the first consumer of renewable energy. In 2021, it consumed 28.4 % of renewable energy worldwide (13.32 EJ), and had an increase of 2.8 EJ of renewable energy. However, that year increased oil consumption by 1.86 EJ, natural gas by1.51 EJ and coal by 3.79 EJ, which makes a total of 7.16 EJ of fossil energy increase, an amount that is 2.6 times higher than the increase in renewable energy.

The second producer of renewable energy is the United States, in 2018 it produced with 18.7% worldwide (7.48 EJ), and had an increase of 0.83 EJ. However, that year, oil consumption increased by 2.81 EJ, that of natural Gas by 0.19 EJ, and coal by 1.37 EJ, the sum of the fossil energy increase amounted to 4.37 EJ, which is 5.3 times higher than the increase in renewable energy.

Germany is the third largest producer of renewable energy (2.28 EJ). In 2021 it consumed 5.7 % of the renewable energy with a decrease equivalent to 0.16 EJ. This year saw a net increase in fossil energy consumption of 0.39 EJ -oil fell by 0.04 EJ, but natural gas increased by 0.12 EJ and coal by 0.31 EJ-.

India is the fourth largest producer of renewable energy, with a world production of 4.5 % (1.79 EJ). In 2021, the consumption of renewable energy increased by only 0.21 EJ. However, it increased oil consumption by 0.33 EJ, natural gas by 0.06 EJ, and coal by 2.69, which makes a total of 3.08 EJ, which is 14.6 times higher than the increase in renewable energy.

Large energy consumers and GHG producers are certainly drivers of renewable energy and the development of clean energy sources. However, some countries, more than others, develop renewable energies specially to cover up appearances. Large fossil energy consumers have not slowed the growth consumption of fossil energy. This explains why the concentration of CO_2 continues to increase in the atmosphere.

VII. Conclusions

It is clear the degree of responsibility, by country, in the release of emissions into the atmosphere. The COPs have sought through diplomacy to commit states to reduce their emissions; 147 countries signed the Paris agreement. However, the facts show that fossil fuel consumption continues to increase without break (*David, 2017*). This indicates that governments have no power or will to induce reductions in both fossil fuel consumption and GHG emissions.

In 2018, the worldwide electricity production increased 3.7%, a figure much higher than the 2.5% growth observed in the previous decade (2007-2017).The atypical growth, was explained by arguing that electricity demand increased due to the extreme weather. Certainly, this year, both the number of hot days and the number of freezing days were exceptional. However, the fact that the weather is increasingly extreme due to increasing energy consumption and CO_2 emissionwas omitted.

Additionally, it was not true that the increase in electricity consumption was due to increased demand for heating and air conditioning. Electricity production in Europe, Japan, and Canada in 2018 was similar to that produced in 2017. The great increases in electricity production corresponded to the three largest electricity producers in the world: China (7.7%), India (6.3%), and the United States (7.7%), and undoubtedly the sector that most forced the electricity demand was the industrial sector, and the mobile was the dispute over world economic supremacy.

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It can be argued that population expansion is the engine of the increase in the demand for energy and the need for goods and services. But the world population grows with a rate of 1.16 %, while world energy consumption with a rate of 1.56 %. If the growth in world energy consumption corresponded to the growth of the population, the consumption of energy, and raw materials could be much lower.

The underlying problem lies in the market economy. The fundamental precept of the market economy is continuous economic growth. For this to be, it is necessary to guarantee a production of excess merchandise and rapid circulation in the market. The market has accelerated through the diversification of financial instruments, the bombardment of publicity, and the increasing obsolescence of goods. The diversification of financial instruments has the purpose of promoting production capacity and, at the same time, providing consumers with a purchasing capacity much more significant than their purchasing power, making them dynamic agents of the economy. Publicity campaigns feed the desire to buy, while reducing the obsolescence times of goods induces the need to buy. Consumers in general, have become unreflective, uncritical, and insatiable, and we are undoubtedly responsible for producing much more than is needed. Consequently, energy and raw materials are consumed in excess and GHG and wastes are released in excess. The market economy is essentially predatory and is responsible for the deterioration of the planet. But consumers are not exempt from liability.

In fact, there are currently insurmountable obstacles to addressing climate change: First, there is reticence to the recognition of the responsibility for the release of GHG by the countries and companies with the highest emissions -whose power and economic growth depend on the exploitation of fossil energy sources-. Second, there is an enormous passivity in the absolute majority of the more than 7800 million inhabitants in the world, to reduce the energy consumption. Third, there are technological and financial constraints. And fourth, there are a relatively small number of people in action; and a political class that, in the absolute majority of cases, remains only on the declaratory plane.

Facing the problem, no longer concerns only the atmospheric sciences; it gradually involves other disciplines that can evolve to be viable. The economy and international law will be obsolete in the face of a climate catastrophe. They will have to keep up, either to reorganize a different economy or for a different world.

Meanwhile, the only true thing is that the only gases that do not produce the greenhouse effect are those that are not released into the atmosphere. Therefore, it is still imperative to reduce energy consumption as much as possible.

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Rangeland Pasture Management Strategies during Drought among Pastoralists in Kajiado County, Kenya

By Rose Mikula
Kenyatta University Kenya

Abstract- Pastoral communities have all along developed local mechanisms for managing forage resources to cope with recurrent severe droughts. Unfortunately, these practices have been suppressed and communities are struggling from losses succumbed by effects of drought on livestock feeds and water. In Kenya pastoral production system supplies the largest percentage of beef to the market as compared to the private sector. However, the study found out pastoralists have inadequate knowledge and sufficient training on pasture management contributing to low level of pasture conservation during periods of excess pasture. The frequently practiced methods were traditional herd tethering and migration. A small fraction of pastoralists adopted and practiced modern systems such as Paddocking, Zero grazing, hay making and use of other supplementary feeds.. In addition, water harvesting technologies to reduce the possibility of rivalry and conflict between and within communities arising from limited water supply during drought should be promoted. There is an urgent call for all stakeholders in the pastoral areas of Kajiado East to establish sustainable strategies to accelerate capacity building in pasture resource management.

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I. Introduction

The world's dry land areas are estimated to cover 41% of the earth surface (Huang et al., 2017; Stewart & Peterson, 2014; Zeng et al., 2021). Pastoralism is considered the most viable production system in these areas and supports over 100 million people globally. This system of production over the years has evolved in areas of the planet, which are harsh and remote on earth (Mingxia et al., 2015). These regions receive rain fall ranging from 25 mm to 600 mm, which varies in quantity. With these conditions, it is clear pastoralists are exposed to a lot of risks as compared to those living in arable lands. The infrastructure in these areas are entirely dilapidated. Nevertheless, these pastoralists have well developed risk-management and adaptation strategies Svejcar & Kildisheva 2017).

In the Greater Horn of Africa (GHA), including the East African Countries, pastoralism is the most upheld economic activity in which millions of people eke out their living (Oluokye, 2003). Pastoralists in these regions build their wealth in number of livestock held. Pastoralists' populations in Horn of Africa countries are estimated to be about 60% in Somalia; 33% in Eritrea; 25% in Djibouti; 20% in Sudan and 12% in Ethiopia (Coppock, 1994, quoted in Ahmed et al., 2001) and Sudan, 80% (Adegoke & Abioye, 2016). Pastoralists regard livestock keeping as source of livelihood, food, financial capital and the basis of wealth. However, this method of livestock production faces challenges such as social, economic, and environmental problems that obstruct their capacity to trap the opportunities.

In the Kenyan arid lands, livestock migration by herders in search of pasture implies the onset of drought. Mothers, children and the elderly who remain behind, forced to rely on charcoal burning, wild fruits, and relief food from aid agencies and governments for survival. Due to shortage of water and pasture herders who had moved with their livestock face the threat of cattle rustling (Nkedienye *et al.,* 2011). Pastoral economy in dry land areas of Kenya constitutes 95% of family income and 90% of all employment opportunities (Kenya ASAL Policy 2012). Due to changing global climate and expected increase in evapotranspiration because of high temperatures, the dry lands are exposed to recurrent climatic extremes such as aridity, water stress and low yields from rain-fed agriculture coupled by severe food insecurity including malnutrition (Thornton and Lipper 2014). Therefore, adequate pasture management strategies crucial to lessen the susceptibility of pastoralists to drought also to prepare them for any future eventualities.

In response to the deteriorating ecology, Maasai pastoralists in Kajiado County have developed mechanisms for survival besides their traditional mechanisms, these included mobility of livestock for forage and water resources, feeding their animals with twigs and branches from trees such as acacia, involving in herd splitting to areas with different ecological zones, livelihood diversification; herd diversification in order to gain from the diverse drought and disease tolerance varieties and promoting formal education for their children through sending them to school as a long term investment in form of income gained from employment, practice of traditional pasture conservation through rotation/deferment from grazing lands according to (Julius et al., 2011).

Author: *Msc. Dryland Agriculture & Enterprise Development, Kenyatta University Kenya. e-mail: mikula260@gmail.com*

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II. Materials And Methods

a) Area of study

The research study was conducted in Kajiado County which has approximately 687,312 households spread across the five wards. It has an area of 19,600 km^2 (CBS, 2009). Most of Kajiado County lies in dry land zones of Kenya. Only 8% of the County's land is potential for rain fed cropping. The region experiences mean annual rainfall which ranges from 300 to 800 mm per annum. With a distribution of bimodal, "short rains" from October to December and "long rains" from March to May. The distribution of rainfall between the two seasons vary gradually (Sombroek et al 1982).The county is semi-arid with temperature range between Figure 1 indicates physical location of Kajiado East Subcounty. The county has five wards as shown in the figure which includes: Kitengela, Sholinke, Kaputie North, Imaroro and Kenyawa-Poka.sholinke is the most populated ward with population density of 34,175 (KNBS, 2012).The county headquarter based at Kajiado town where administrative functions and offices are located.

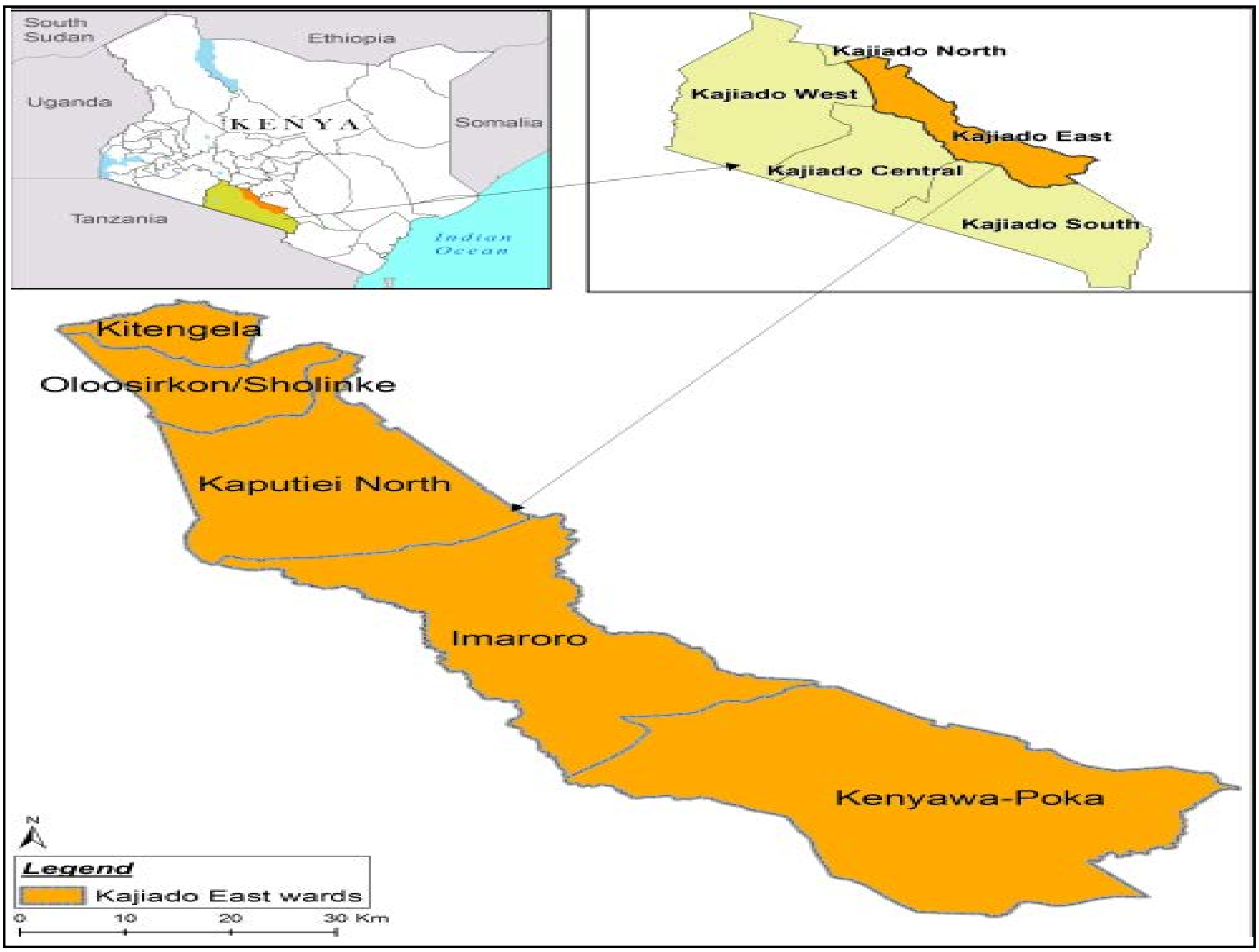

Figure 3.1: Map of Kajiado County- administrative Boundaries (Constituencies in Kenya © 2018)

The Kajiado County community practice pastoralism as a source of livelihood. The indigenous inhabitants (mainly Maasai ethnic community) have lived in the area for a long period of time to identify with the effects of changing climatic and environmental conditions. In the recent past, drought has been a frequent phenomenon in the region, yet these pastoralist groups have not abandoned their livelihood strategies to adopt other means of survival. Therefore, it was significant to assess the underlying pasture management strategies practiced by the community to cope and recover from persistent drought effects.

b) Research Design

The study was carried out using cross-sectional survey design. The rural communities who depend on pastoralism were the target population for the study. Kajiado East Sub County has a population of 136,482 persons (KNBS, 2012). For the purpose of this research 385 households were selected randomly from the 5

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wards namely: Imaroro, Kitengela, Kenyawa-Poka, Oloosirkon and Kaputiei North to form the sample size.

Quantitative and qualitative data were collected using pre-tested questionnaires administered by trained enumerators at the household level. Biophysical characteristics such as vegetation type, sources of water, water use and management and communal practices employed to manage pasture during drought were collected. Qualitative data on effect of drought on pastoralists, pasture management strategies and coping strategies was collected from five focus group discussions (FGD) in each ward. This was carried out with older herders who have wide range of knowledge on animal feed management, having experienced several droughts and great ideas on what the community has always done to manage their pasture and ensure their survival.

c) *Sample Site and Size determination*

The sample site were Imaroro, Kitengela, Kenyawa-Poka, Oloosirkon and Kaputiei North. This was because, the locations were inhibited by pastoralists who have lived in the area for over ten years and were best place to provide objective result for study.

The sample size was determined using the formula for maximum error of estimates as proposed by Mugenda and Mugenda (2013) and Amugune (2014).

$$n = \left(\frac{Z \frac{\alpha}{2} \delta}{E} \right) 2$$

Where:

n is the sample size

$Z \frac{\alpha}{2} \delta$ Refers to the normal distribution at 95% confidence level,

E is the standard error. E is 0.1 so the sample mean is 10% outside the population mean. However, using 95% confidence level, it is assumed that the sample mean fell within the population mean. This formula was used because there was no assumed mean of the population and therefore the sample mean was only calculated using the maximum error estimates that allowed the sample size to fall within the population mean. With formula above, a sample size of 385 was identified.

Table 3.1: Sample distribution in selected wards in Kajiado East Sub-county

County wards	Number of households	Percentage of total	Sample distribution
Kaputie Ward	29,989	20.3	78
Kitengela	30,663	20.8	80
Oloosirkon/Sholinke	34,175	20	77
KenyawaPoka	24,559	19.5	75
Imaroro	17,096	19.5	75
Total	136,482	100	385

Source: GOK National Census 2009

d) *Data Collection and Analysis*

i. *Data collection*

The study collected primary and secondary data.

- *Focus Group discussions (FGD);* Five focused group discussions were done with representatives from animal herders, women groups, community elders and representatives of community-based organizations, to acquire useful and detailed information on drought effects in the area, pasture management strategies during drought and coping strategies used by the pastoral community.

- *Administration of Questionnaires;* Quantitative and qualitative primary data were gathered using pre-tested questionnaires administered to the pastoralists. Enumerators from the local community were identified and trained on how to administer the questionnaires on the basis that they could speak the local language and understand the geographical area. After training, the enumerators, pretested questionnaire were pretested in the neighboring Kajiado West sub county. Thereafter, necessary modifications were made on the question-naires before the actual data collection began. The semi-structured questionnaires were used to collect information on household size, demographic structure, literacy level, and marital status, pasture management strategies, effects of drought on livelihood and animals, drought coping strategies and pasture recovery mechanisms.

ii. *Data Analysis*

The completed questionnaires were cross-checked for completeness and consistency before analysis. SPSS (Statistical package for social science Version21.o) Microsoft Excel was used to generate descriptive charts and graphs and other functions. Microsoft word processing tools were used to analyze Qualitative data. Processed data was presented using tables, graphs and pie charts to give visual display of findings. Descriptive statistics was used to analyze the data gathered for development of indices from the raw data and included frequencies and percentages. The data from FGDs for proper understanding and confirmation to the quantitative data collected from the community, was organized into themes and sub-themes.

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III. Results and Discussion

a) Results and Discussion

i. Socio-economic and demographic characteristics of the respondents

Socio-economic and demographic characteris-tics of the respondents varied as shown in Table 4.1).

Table 4.1: Household socio-economic and demographic characteristics of respondents

Socioeconomic factors	Characteristic	Percentage
Marital Status	Married	65
	Divorced	4
	Widowed	21
	Single	10
		100
Type of Household	Male headed	75
	Female headed	25
		100
Number of people per household	0-5	26
	6-10	61
	11-15	10
	Over 15	3
		100
Literacy status	Did not attend school	77
	Lower primary (1-4)	8.8
	Upper primary (5-8)	8
	Secondary school	4
	College (diploma/Certificate)	1
	University	1.6
		100
Source of Family income	Formal employment	2
	Pastoralist	57
	Hired herdsman	2
	Farming	7
	Housewife	17
	Unemployed	2
	Businessman/woman	13
		100
Livestock herders during drought	Children/boys	13.3
	Youth/Moran	43.6
	Men aged 30 and above	43.1
		100
Number of Years lived in the area	<5yrs	8.2
	5-10yrs	43.9
	>10yrs	47.9
		100

The results showed that (75%) of the households were male headed and 25% female headed. About 65% of the respondents in the study area were married, widowed, single, and divorced. Slightly over 60% of the households have relatively medium family size (6-10 members) while less than 30% have small family size (0-5 members), and 13% of the households had a large family size (over 11 household members). The results revealed that literacy level in the study area was low as the majority (76%) of the respondents had informal education relative to only 24% of the respondents who had attained formal education.

There were diverse economic activities in the region (Table 4.1). The respondents being pastoralists, their main economic activity was pastoralism (57%). Crop production (farming), taunted as the upcoming economic activity was 7%, while hired herdsman contributed 2% of the economic activities of the study area. Both formal employment and unemployment were very low (2%). The majority of the unemployed were women 17% of them were housewives. On the other hand, it was found that almost half (48%) of the residents had lived in the study area for more than 10 years, while slightly over 40% had lived between 5-10 years while only a few people (8%) had stayed for less than 5 years. The result also indicates that adults (87%) attended to the herds during the drought period as opposed to children (13%).

Socio-economic attributes of a population are important in understanding the behavior of the people.

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The study revealed that the majority of the pastoralist are married thus implies that they are family-oriented. Nonetheless, the pastoralists are conservative and have strict on gender roles hence the 25% female headed households was attributed to death of husband, divorce or single parenthood. Gender is important in access to resources and participation in community affairs in pastoralist communities. Similar studies have reported effect of gender on resources access and access to education in Tanzania (Campbell, 2021; Lusasi & Mwaseba, 2020). Gender inequality could explain the low economic development in the study area. Altuzarra et al. (2021) found positive correlation between gender inequality and low economic growth in developing countries.

This study found low level of literacy within the study area which could be ascribed to the economic status of the pastoralists, value placed on livestock and gender bias in access to education (Kaul, 2015). The low literacy level could also explain the few people informed in formal employment (Table 4.1). The findings of this study resonates with the results of Lowe et al. (2021) who found that young pastoralists' girls are denied access to basic education as they are married at a very tender age. The low education level could possess a significant impact on development and technology uptake by the community (Abu-Shanab, 2011; Riddell & Song, 2017). About 75% women in Kajiado are housewives which could be associated with cultural conservation of the pastoralists. Other scholars have opined that this could be attributed to fear on power dynamics among the communities and a hinder women career choice and growth (Ford et al., 2021; Mtey, 2020; Olga et al., 2020).

b) *Effects of drought on pastoral areas of Kajiado East Sub-county*

i. *Effects of drought on pasture production and management*

Drought occurrences have several effects on pasture production in Kajiado County as shown in Table 4.2. The majority of the respondents (60%) opined that droughts lead to loss of pasture while slightly over (23%) of the interviewees suggested that the climatic event causes death of their livestock. Other respondents (8%) reported that an occurrence of drought lowers their selling price while others felt that droughts cause loss of family income (5%). However, only a few respondents (4%) associated drought to tribal conflicts. On pasture management strategies, they proposed a range of pasture management strategies. Slightly above 40% of the respondents suggested training on pasture management while rain water harvesting and use of irrigation were proposed by (30%) and (25%) of the respondents, respectively.

Table 4.2.1: Effects of drought on pasture production and management

Characteristic	Parameter	Percentage (%)
Effects of drought experienced	Loss of pasture	60.2
	Death of livestock	23.5
	Low selling price	7.6
	Loss of family income	4.5
Total	Tribal conflict	4.2
		100
Measures to manage pasture during drought	Water harvesting	30.0
	Practice of irrigation	24.6
	Training on pasture management	41.4
Total		100

The study found diverse ways in which drought affects pastoralists in Kajiado County. The effect ranges from economic to social vices. This could be attributed to the fact that livestock is the mainstay of the community as depicted in Table 4.1. This finding is in agreement with the results of Frank et al. (2014) who found that drought increased the need for more income and reduced mobility of the pastoralists. Furthermore, the finding can be ascribed to Kajiado being situated in the ASAL parts of Kenya and which is most vulnerable to effect of prolonged droughts as a results of climate change (Mogotsi et al., 2013). The pastoralist community depend on natural resources and therefore inadequate water and pasture due to drought translates into huge effect on pastoralist's livestock production which could often lead to conflicts. Similar results have been reported among pastoral communities in Somalia, Ethiopia and Kenya (Africa, 2021; Fava et al., 2021; Jibat & Abashula, 2020). Other researchers have also found a positive correlation between drought severity and livestock losses in pastoral region (Huho and Mugalavi, 2010; Nkedienye et al., 2010).

c) *Pasture management strategies by pastoralists in Kajiado Sub-county*

i. *Household pasture management strategies*

There are numerous pasture management strategies adopted by pastoralist's community in Kajiado County as shown in Table 4.3.

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Table 4.3.1: Household pasture management strategies

Characteristic	Parameter	Percentage
Have animal feed reserves during drought	Yes	24.9
	No	75.1
		100
Strategies used to manage pasture by the pastoralist	Herding	29.7
	Paddock grazing	42.2
	Buy hay	28.
		100
Most considered method of pasture management during drought	Paddocking	68.3
	Herd splitting	21.8
	Rotational grazing	8.5
	Migration	1.4
		100
Sources of feed during drought	Natural forage	81.3
	Use of concentrates	5.1
	Buy Hay	13.6
		100

Paddock grazing accounted for (42.2%), herding of animals (29.7%) while buying of hay was (28.0%) (Table 4.1. The majority (80.5%) of community emphasized that they move (mobility) with their livestock during droughts. Although most pastoralists own land) hay making has not been taken up seriously with majority of the pastoralists' reliance on natural resources. The results of this study found that paddocking is the most preferred method of pasture management by the Kajiado pastoralists. This could be attributed to the flexibility of the method to accommodate the herds throughout the year. This assertion is supported by other researchers who reported the same results elsewhere (Tawe, 2018; Korir, 2020). The adoption of rotational grazing by the pastoralists probably was because of its ability to allow vegetation and soil a resting time to recover, and to improve vegetation conditions hence enhancing conservation and production goals (Roche et al., 2015). In addition, Vecchio et al. (2019) found that rotational grazing improved conditions of grassland containing halophytic steppe as opposed to continuous grazing. On the other hand, Augustine et al. (2020) found that rotational grazing method is an adaptive strategy and improves the performance of both pasture and livestock.

Herding was also practiced as a pasture management strategy by 29.7% of the respondents. Probably this method is practiced because often herd mobility is restricted during droughts hence abled men move with the livestock in search of water and pasture. Similarly, herders in Northern Norway adopted herding as pasture management and adaptive strategy (Risvoll & Hovelsrud, 2016). Moreover, the preference for herding by the community could be attributed to the advantages of the herding which include; low expenses for fencing or water supply, one herdsperson looks after hundreds of animals which reduces the cost of labor, uncontrolled livestock movement so they enjoy plenty of exercise and browse a variety of forages thus maintaining high nutrition and production level of animals, and provision of the livestock a stress-free environment. The method could have also favored people with limited land size. The findings of this study are in agreement with the results of other researchers who found increased advantages of herding like improved management of pasture species (Molnár et al., 2020), better management of biodiversity (UNESCO, 2016), and improves sustainability and resilience of the pasture ecosystems (Riseth et al., 2016).

It was noted that buying hay was unpopular among the pastoralists and this was attributed to the fact that they do not conserve pasture before droughts and during rainy seasons. Furthermore, this could be as a result of the community over relying on natural resources as was also noted in a study conducted in the same County (Yala et al., 2020). This finding resonates with that of the study conducted in the Great Plains where buying hay was found to depict preparedness of the pastoral communities but which was adopted to a lesser extent (Haigh et al., 2019). Buying hay offers perfect opportunity to pastoral communities to cope and adapt to droughty situations (Salmoral et al., 2020). The pastoralist community in Kajiado could greatly benefit in storing hay and forage as a coping strategy during droughts as was noted Mongolia (Hansson, 2020).

ii. *Relationship between pasture management and establishing feed reserves*

The relationship between pasture management and establishing feed reserves is shown in Table 4.4.

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Table 4.3.2: Relationship between pasture management and establishing feed reserves

Understanding pasture management	Have established feed reserve		χ2	P
	Yes	No		
Yes	33 (9%)	117	1.196[a]	.166
No	55 (21%)	148		

There was no significant association (p = 0.166) between understanding pasture management and establishment of feed reserves. This finding could be explained by the fact that the majority of the pastoralists did not reserve feeds as they depend heavily on natural grassland (Yala et al., 2020).

iii. *Pastoralists sources of information on pasture management*

The respondents obtain information on pasture management from different sources (Fig. 4.1). Television (TV) was the most preferred (37% source of pasture management information. The respondents also obtained information from mobile phones, radios, extension officers and NGO training (30, 16, 14 and 3%, respectively).

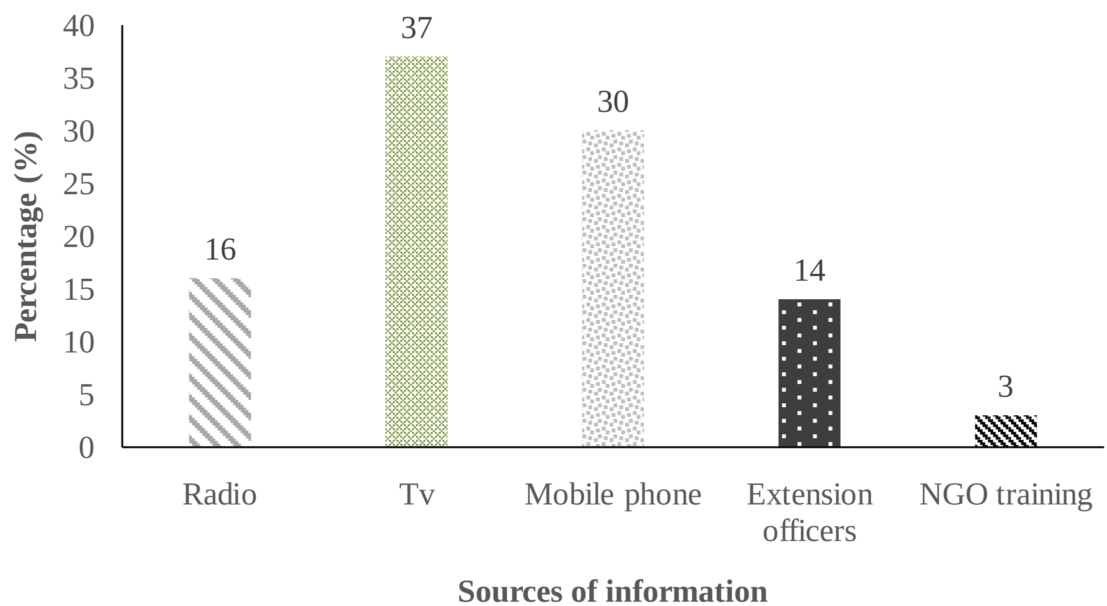

Figure .3.2: Household sources of information on pasture management

Pastoralists in Kajiado obtain pasture management information from both electronic sources and training from extension officers and NGOs. This could be attributed to improved infrastructure like network and electric connectivity in the County (Annemiek, 2018; Schrijver, 2019). Also, this could be associated with the improved accessibility of the County agricultural extension officers (Edwin et al., 2018). Given that Kajiado is among the vulnerable communities, the involvement of NGO in training farmers could have been supported by improved partnership between the Kajiado County Government and development partners (Haan et al., 2016). NGOs play critical role in institutional development and shaping policy framework in pastoral regions (Ofoegbu et al., 2018).

d) *Drought coping strategies in Kajiado East Sub-county*

i. *Pastoralists drought coping strategies*

Pastoralists in Kajiado County have various coping strategies towards the effect of drought as explained in Table 4.4.1. The most popular coping strategy was varying livestock numbers to correspond with the diminishing forage (81%). The respondents suggested that this strategy is used to cope with effects of drought. Only a few (19%) did not regard this as a coping strategy but felt it is a result of the changing reproduction rate (8%). The other popular strategy was breeding replacement stock (79%) as only 21% of the respondents viewed buying of herds after occurrence of drought as a coping strategy. The pastoralists use different sources of water which include boreholes, tap water (26%), and dam (73%), (26%) and (1%), respectively. The study found preference of forage types

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during droughty periods. The community most preferred pasture was *Brachiariahumidicola* (97%) during the drought while *Pennisetum purpureum* Schumach is only preferred by a few respondents (3%).

Table 4.4.1: Household drought coping strategies

Characteristics	Parameter	Percentage
Varied herd numbers to correspond with diminishing forage	Yes	81.3
	No	18.7
		100
Replenished/Restocked herd after drought	Bought	21.2
	Bred the replacement stock	78.8
		100
Sources of water for domestic use	Boreholes	73.4
	Tap water	25.5
	Dam	1.1
		100
Most preferred pasture species	*Brachiariahumidicola*	96.6
	Pennisetum purpureum Schumach	3.4
		100
Migration	Yes	29.7
	No	70.3
		100
Sustenance of female-dominated herds	Yes	68
	No	32
		100
Keeping different types of animals	Yes	56
	No	44
		100
Rotational grazing	Yes	71
	No	29
		100
Diversification to crops:	Maize	34.9
	Pearl millet	12.2
	Finger millet	11.4
	Sorghum	15.1
	Cowpeas	9.2
	Beans	17.2
		100

Pastoralists in Kajiado practice a number of coping strategies ranging from change in herd structure and management to diversification of livelihood which entails crop farming. These diverse coping strategies could be associated to deliberate efforts by the pastoral communities to build resilience and reduce vulnerability to effects of climate change (Fava et al., 2021; Guye et al., 2019; Ndiritu, 2020; Ndungu et al., 2021). The migration with the herds could be associated with the desire by the pastoralists to sustain carrying capacity before they reach the place. According to Guye et al. (2019), herd mobility enables strategic use of resources and helps to reduce the effect of drought and dry spells. As suggested by Mcguirk & Nunn (2021), migration probably ensures that the households retain the productivity of their livestock and security of the family. The pastoralists probably prefer keeping female herds during droughts because of production of milk for domestic consumption and an indicator of wealth. Similar results were reported by who pastoralists in Kenya not only keeps female herds during drought but also as an approach to meeting market demands (Mcguirk & Nunn, 2021). The results also showed that the community diversified into crop production with focus being on drought tolerant crop varieties. These crops require minimal water resources and in agreement with studies done byWilk et al. (2013) and Ncube and Lagardien (2015).

e) Variation in pastoralists' uptake of drought coping strategies

The study sought to determine how much variation in pastoralists' uptake of drought coping strategies could be explained by some socio-economic factors through linear regression analysis. The used were the number of animals owned, land ownership and understanding pasture management. The coefficients of parameters used to determine variation in pastoralists' uptake of drought coping strategies are shown in Table 4.4.2.

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Table 4.4.2: Coefficients of Parameters Used to Determine Variation in Pastoralists' Uptake of Drought Coping Strategies

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	0.475	0.177		2.688	0.008
Number of animals owned	0.130	0.070	0.166	1.861	0.015
Land ownership	0.108	0.097	0.096	1.112	0.026
Understanding pasture management	0.184	0.070	0.236	2.615	0.010

a. Dependent Variable: Uptake of drought coping strategies

From the table 4.4.2, the coefficients of the established regression equation are:

$$Y = 0.475 + 0.130a + 0.108b + 0.184c + €$$

Where: a - Number of animals owned
b - Land ownership in acres
c - Understanding pasture management
€ - Error term

Table 4.4.2 shows that the three variables are important factors in enhancing pastoralists' uptake of drought coping strategies. The regression equation revealed that the number of animals owned, land ownership and understanding pasture management to a constant zero, pastoralists' uptake of drought coping strategies would be 0.475. However, understanding pasture management (0.184) has greater effect on pastoralists' uptake of drought coping strategies followed by number of animals owned (0.130) and lastly land ownership (0.108). This implies that embarking on either of the variations would improve pastoralists' uptake of drought coping strategies and hence minimize drought associated losses among pastoralists.

Table 4.4.3. indicates that (61%) of the variation in pastoralists' uptake of drought coping strategies could be attributed to number of animals owned, land ownership and understanding pasture management strategies implying that the model is a good fit for the data.

Table 4.4.3: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.653[a]	0.611	0.608	10.63

a. Predictors: (Constant), Number of animals owned, Land ownership and Understanding pasture management

From the ANOVA statistics in table 4.4.4, statistically, the overall relationship was very significant with significant value, P value = 0.000, ($P < 0.01$)

Table 4.4.4: ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2.254	3	0.751	5.690	0.001[b]
	Residual	15.843	120	0.132		
	Total	18.097	123			

a. Dependent Variable: Uptake of drought coping strategies

b. Predictors: (Constant) Number of animals owned, Land ownership and Understanding pasture management

IV. General Discusion, Conclusions and Recommendations

a) General Discussion

This chapter gives summary of study from introduction to data analysis. The research study sought to evaluate pastoralists pasture management strategies during drought with main focus areas Kajiado County in Kenya. The chapter presents a summary of study objectives, research methodology and findings. The various discussion topics were based on research objectives: To describe socio economic and demographic characteristics of pastoralists in Kajiado County. To evaluate the effects of drought on patoral areas of Kajiado County. To assess pasture management strategies of pasoralists in kajiado County. To determine drought coping strategies of pastoralist in Kajiado County.

b) Conclusions

The general study objective was to evaluate rangeland pasture management strategies during drought among pastoralists in Kajiado County with main

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focus Kajiado East Sub County. The following were the results (i) The study findings showed the semi-arid region was inhabited by pastoralism and mixed economy. Whereas mixed economy included rain fed and irrigated agriculture, agro pastoralism, tourism related activities, small businesses based on dryland products like beading.(ii) Marriage was highly regarded and most households were male headed, education uptake was low with majority of studied population recording no formal education. In addition, studied nuclear families consisted averagely of 6 family members. The findings showed family size determined responsibilities and exposure significantly. It was further analysed that the community under study kept livestock such as Goats, Sheep, Cattle and donkey the least reared was poultry.

The study also found the areas were frequently hit by drought and water scarcity subjecting pastoralist community to livestock deaths, decreased livestock production, low selling price, loss of family income and tribal conflict during migration and scramble for pasture. From study it was evident existing water resources were dams, bore holes few rivers and tapped water implying that the community lacked adequate water source to cushion them during droughts. It was evident most of pastoralists within the study area did not have enough knowledge on pasture management and this contributed to the low level of pasture conservation during periods of excess pasture. The frequently practiced pasture management strategies were traditional methods of herd tethering and migration. Other pasture management systems such as Paddocking, Zero grazing and use of other supplementary feeds including hay were practiced by few pastoralists. The study also showed pastoralists lacked adequate skills on pasture management strategies sighting lack of local trainings on best practices to enable establishment of strong buffer for their livestock during drought.

Recommendations

In line with the study findings and conclusions drawn, the following recommendations were made.

1. The pastoralists needed to be equipped with trainings on modern range pasture management to enable them effectively preserve the excess forage as hay making and silage making strategies were not actively taken up during rainy season to reduce the effect of drought as a result of limited pasture.
2. The community should adopt modern water harvesting technologies to reduce possibility of rivalry and conflict between and within communities arising from limited water supply especially during drought.
3. The community should Partner with local government and NGOs to provide financial support to the herders during drought in terms of mass purchase of their livestock to reduce losses experienced when animals die due to insufficient water and forage.
4. There was need to strengthen community traditional pasture management strategies by sensitization of pastoralists on modern practices.

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We accept the manuscript submissions in any standard (generic) format.

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Alternatively, you can download our basic template from https://globaljournals.org/Template.zip

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Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

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3. Ensure corresponding author's email address and postal address are accurate and reachable.
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5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

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Acknowledgments

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Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

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Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

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Tips for Writing a Good Quality Science Frontier Research Paper

Techniques for writing a good quality Science Frontier Research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of science frontier then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

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References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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