

Is Salicylic Acid the Key to Cost-Effectively Scaling Biochar on Drought Prone Lands?

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“In arid regions, one of the practical solutions to overcome the water shortage and increas[e] soil fertility is the application of salicylic acid (SA) with biochar.”—Research Paper #3, September 2024, (see Appendix)

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Statement on My Use of AI

When searching for information that is not found in trusted sources, such as *Google Scholar*, I often use four different AI platforms—Perplexity.ai, DeepSeek, Gemini, and Chat-GPT. I then compare the results. These four platforms are all trained on different training data, which minimizes the chances of bias, due to incomplete training data. It also minimizes the chances of accepting “hallucinations” that any of the platforms might generate. I will sometimes edit the AI platform’s output to correct or add to what it outputs. I welcome questions about my use of AI.

Summary

A **four year (2021-2024) field study** on rain-fed fig trees in a semi-arid region of Iran was published on July 8, 2025. Entitled “Salicylic Acid and Biochar-BioFertilizer Improve Soil Fertility, Drought Tolerance, and Fig Yield in Semi-Arid Region”, it described a **300% increase in fig yield** and a **3.99 benefit-to-cost (B/C) ratio, compared to a 0.29 B/C ratio for the control (no SA, biochar, or biofertilizer—13.75 times better)**. All of the 21 metrics, such as taste, nutritional content, and marketable grade, also improved significantly. The salicylic acid (SA) was applied as a foliar spray.

My search on Google Scholar, using the key words “biochar”, “salicylic acid”, and “increased yield” revealed “about 605” papers. Salicylic acid’s benefits appear to be better known in resource-constrained developing countries than in developed countries, which primarily rely on mechanization to counter climate change induced challenges.

One major benefit of Salicylic acid (SA) is that it is *the* plant hormone that is key to protecting plants over both the short and long terms against *biotic* stressors, such as many different kinds of pests. Most importantly for areas that are suffering the ever increasing effects of climate change and soil degradation, SA greatly enhances plant tolerance to *abiotic* stressors, like drought, heat, cold, as well as soil salinity and heavy metals.

SA is inexpensive and widely available globally as a powder. It must be highly diluted in water at 0.01% to 0.04% (w/v) for foliar application, for addition to irrigation water, or to coat seeds for priming. Optimal dilution factors are critical to success and require field testing.

SA works *synergistically* with charged biochar. The biochar improves the soil's water holding capacity and provides plant symbiotic microbes for nutrient cycling. Exogenous SA works from *inside* the plants to harden them to both biotic and abiotic stressors. The combination can improve plant outcomes by much larger amounts than either could achieve alone.

Dilute SA is very inexpensive and easy to apply, especially to fields that already have biochar in their soils. Once a year applications are normally sufficient. SA plus charged biochar can be combined with other practices, such as organic farming and conservation agriculture.

Introduction

According to the [“2025 Global Drought Outlook”](#) from the OECD (Organization For Economic Cooperation and Development), “40% of the world's land area faces increasingly frequent and severe droughts.” Furthermore, the average annual increase in the economic cost of a drought episode is 3% to 7.5%. The minimum projected increase in drought related economic losses by 2035 is 30%.

The OECD report continues, “In Somalia alone, an estimated 43,000 excess deaths may have occurred in 2022 due to the severe drought, and over one million Somalis were displaced...Malnutrition is one of the most severe direct health impacts of drought, with children under 5 and women being the most vulnerable populations?”

While the biochar industry worldwide, with the leadership of iBI, USBI, EBI, ANSBIG, and others, has made impressive strides to mitigate climate change with CDR, much of the government and private funding for CDR is being mis-spent on much less cost-effective methods. ***Consequently we are on a trajectory that is likely to result in many of climate change's worse consequences, including massive food and water insecurity that will cause huge forced migrations, unlike any we have seen so far. We need to scale biochar much faster.***

Like many others, I got into biochar because I believed it was the best way to mitigate climate change, while also providing many other important benefits to the environment and humanity. One of my ways of doing that was to try to follow the biochar research papers and to search for ones that looked both technically viable and cost effective. With over 6,000 biochar research papers published per year, I soon realized that was an impossible task.

Fortunately, *Biochar Today* arrived in 2024 and they selected what they believed were the ‘best’ of the recently published papers and provided synopses of them. That was a big help.

Still, most of those papers were short term lab studies, which contained no economic data. What I’d hoped to find were long term compelling field trials that included impressive yield, quality, and cost/benefit data.

One such study appeared in *Biochar Today* on July 21, 2025. It was entitled, “Combined 1.0mM Salicylic Acid and Biochar-Biofertilizer Treatment Boosts Fig Yield by Over 300% and Soil Water Content by up-to 55%”. I was happily surprised to find that the paper described a process that appears to be a viable way to rapidly scale biochar use in regions that are drought and heat stressed, in both developing and developed countries. (That now includes a large part of the world.)

Research Paper #1: Four Year Field Study

On July 8, 2025 a peer reviewed research paper was published in the prestigious *Journal of Soil Science and Plant Nutrition*. It was a four year (2021-2024) agricultural field study of a rain-fed fig grove in a semi-arid part of Iran. (See the end of the *Biochar Now* article to download a copy of the complete paper.) The paper describes an approach that I believe has the following advantages. It:

- Could be easily implemented on both rain-fed and irrigated crops
- Addresses several climate change stressors: drought, heat, pests, etc.
- Increases yields and quality, beginning in the first growing season
- Could be used to promote food and water security worldwide
- Could utilize current agricultural methods, equipment, and practices

- Could promote the rapid scaling of biochar for significant CDR impact
- Includes a detailed cost/benefit analysis with impressive results
- Does not require the use of carbon credits to be cost-effective

I highly recommend reading the *Biochar Today* synopsis of the paper to learn about the **300% yield improvement, major increases in fig sizes and numbers, improved flavor**, plus the **3.99 benefit-to-cost-ratio vs. 0.29 for the control group** of fig trees. (The researchers used biochar made from the slow pyrolysis of fig tree prunings in a solar powered stainless steel chamber at 500C for 4 hours.) At the end of the *Biochar Today* synopsis there is a button which will allow you to download the full paper.

From the *Biochar Today* summary, “The most compelling outcome of this research was the significant impact of the combined treatments on fig fruit yield and quality. Salicylic acid (SA) application alone, particularly at 1.0 mM, more than doubled the dry fruit yield from 7.93 kg/tree in the control to 16.49 kg/tree. This concentration also improved fruit size distribution, reducing small fruits and increasing medium and large sizes...”

The summary continues, “Similarly, the biochar and biofertilizer combined treatment (B2) nearly doubled the dry yield, reaching 16.70 kg/tree compared to 8.06 kg/tree in the control. The synergistic effects truly shone when SA was combined with the biochar-biofertilizer treatment. The optimal 1.0 mM SA + B2 [biochar plus organic fertilizers] combination resulted in the highest dry fruit yield of 23.61 kg/tree. This represents an increase of over 300% compared to the control (SA0.0 mM + B0), which had a yield of 5.63 kg/tree. This combination also significantly improved fruit quality parameters...”

It is interesting that the addition of foliar SA alone increased the yield by virtually the same amount as the addition of biochar and bio-fertilizer alone. In both cases, they increased the yield by 100% or more. **When combined at the optimal SA concentration, they increased the yield by over 300%! (1+1 = 3)**

Salicylic Acid (SA) Acts Synergistically with Charged Biochar

Salicylic acid (SA) is one of six plant hormones. Only discovered in the 1990s, it is known for its central role in safeguarding plants against diverse threats. It is a key signaling molecule in **Systemic Acquired Resistance (SAR)**, a long-lasting, broad-spectrum defense, activated against biotic stressors like pathogens. Following an initial infection, SA accumulation triggers the expression of pathogenesis-related (PR) genes, fortifying plant tissues against subsequent attacks for extended periods.

SA is also crucial for **mitigating abiotic stressors**. It helps coordinate protective responses to environmental challenges such as **drought, extreme temperatures, as well as salt and heavy metal soil toxicity**, by modulating various physiological processes. This includes closing leaf stomata to conserve water, activating antioxidant systems to scavenge harmful reactive oxygen species, and regulating stress-responsive gene networks.

While plants create and regulate their own SA, it can also be applied exogenously via foliar application, as part of irrigation water, or as a seed coating in priming. Whichever application method is used, typically, SA only needs to be applied once, early in the planting season. It is important to measure the very low concentration of SA in water. It should be neither too high or too low. (Too high concentrations can depress results, just as too low concentrations can.) Trials should be run at various dilution levels to bracket the optimal concentration before applying it more broadly.

In short, salicylic acid (SA) acts as the internal hormonal signal, while the biochar and microbial community, including fungi, create the optimal external environment, mainly the soil conditions, to trigger and sustain those signals.

No Other Plant Hormone Can Do Everything That SA Does

Salicylic acid (SA) plays a crucial role in plant growth, development, and response to environmental stress. While it shares some functions with other plant hormones, it has specific unique roles that differentiate it from them. Here are some key functions and advantages of salicylic acid:

1. **Systemic Acquired Resistance (SAR):** Salicylic acid is a key signaling molecule in the establishment of systemic acquired resistance, which is a form of induced resistance that enhances a plant's ability to defend against a broad spectrum of pathogens, even over a long period of time. While other hormones, like jasmonic acid (JA), and ethylene are also involved in stress responses, SA is specifically linked to defense against pathogens. In that sense, it is like a vaccine that is activated by the attack of a specific pathogen.

2. **Stress Tolerance:** Salicylic acid enhances plant tolerance to abiotic stresses like drought, heat, cold, plus salinity and heavy metals in soils. It acts by modulating physiological processes, including stomatal regulation and water retention, which may not be as effectively managed by other hormones.

3. **Antioxidant Properties:** Salicylic acid can act as an antioxidant, helping to stabilize membranes and reduce oxidative stress in plants. While other hormones may have roles in promoting growth or stress responses, SA's specific ability to mitigate oxidative damage makes it distinct.

4. **Regulation of Photosynthesis:** SA has been shown to enhance the efficiency of photosynthesis under stress conditions by regulating chlorophyll content and photosynthetic enzymes. Other hormones may influence growth and development, but do not specifically optimize photosynthetic processes in stress contexts.

5. **Modulation of Gene Expression:** Salicylic acid has a unique ability to regulate the expression of specific genes involved in defense responses. It can activate various pathogenesis-related (PR) genes that are not necessarily influenced by other hormones.

6. **Interaction with Other Hormones:** Salicylic acid can modulate the effects of other plant hormones, such as auxins, gibberellins, and cytokinins. For instance, it can enhance the sensitivity of plants to these hormones or counteract their growth-promoting effects under certain conditions, allowing for a finely tuned regulatory approach to plant responses.

In summary, the unique effects of salicylic acid—especially in defense signaling, stress tolerance, and antioxidant activity—distinguish it from other plant hormones and underscore its importance in plant biology and agriculture.

Cost and Availability of Agricultural Salicylic Acid

Plant and animal hormones are very powerful at ultra-low levels. Externally applied SA, whether in foliar application, by adding it to irrigation water, or via seed priming, is most effective at specific very dilute concentrations. In fact, if the SA concentration is too high (or too low), it will be less effective.

SA is widely used to make skin care products, like acne creams. There are two ways to make agricultural SA, which is sold in powder form to be dissolved in water. “Synthetic” agricultural SA is produced using classic chemical processes (Kolbe-Schmidt Process) from fossil fuel-based feedstocks, whereas “organic” SA is extracted or biosynthesized from plant materials (willow), using enzymatic or fermentation pathways.

“Organic” SA is significantly more expensive than synthetic SA. It is made in much smaller volumes and may not be available in all parts of the world. Agricultural grade synthetic salicylic acid is **widely available** in most major economies and agricultural regions worldwide, either directly through domestic production or as an importable good. For that reason, I will henceforth mean synthetic agricultural SA, when describing SA.

Of course, if a farmer prefers to use organic SA and it is available, he or she can certainly opt for it. The overall cost will still be very low because it will be highly diluted.

From a climate change perspective, the amount of fossil fuel used to make the synthetic agricultural SA at the dilution levels needed will be so much smaller than the benefits gained from scaling biochar and feeding people who would have otherwise gone hungry that it is an easy decision to choose to use synthetic agricultural SA.

In the first research paper, three levels of SA were tested—0.5 mM, 1.0 mM, and 1.5 mM. (“mM” is an abbreviation for millimolar. One millimolar

equals one millimole of solute per liter of solution.) In that paper, the optimal concentration was 1.0 mM.

In the second paper, only one level of SA was tested—3.0 mM. 1.0 mM of SA in water equates to 138 mg/L or 138ppm. 1% of anything is 10,000ppm. Thus a 1% solution of SA would need to be diluted 72 times to get down to 138ppm. 3.0 mM would equate to $3 \times 138\text{ppm} = 414\text{ppm}$.

In the third research paper that I examined (see Appendix), three concentrations of SA were used—50, 100, and 150ppm. The optimal level was 100ppm, which equates to $100\text{ppm}/138\text{ppm} = 0.72\text{mM}$. Based on the research papers I have examined so far, the optimal concentration should be between 0.5 mM and 2.0 mM, although it could be as high as 4.0 mM. 0.5mM increments are ideal. The objective of the trials is to ‘bracket’ the optimal concentration—neither too high nor too low. SA’s efficacy declines both above and below the optimal concentration.

The latest data indicates that the price for salicylic acid in the United States in Q3 2024 reached approximately \$3,700 per metric ton (MT). Since 100 pounds equals about 45.36 kilograms (0.04536 MT), this translates to roughly \$168 for 100 pounds in bulk. This figure reflects typical industrial or plant-grade pricing for large volume buyers in the current U.S. market.”

10 pounds of powdered highly diluted SA, which would cost less than \$50.00 US, would be more than enough to treat over a thousand acres of farmland, whether by foliar application, as part of irrigation water, or as a seed coating.

Even at considerably higher unit costs for lower volumes, the overall cost of using highly dilute solutions of SA for agricultural applications will be minimal. Shipping cost should be reasonable because the SA is shipped as a powder with no water. Whether the SA is applied as a foliar, as a very small part of irrigation water, or as a seed coating, the labor and equipment cost of applying it should be low, especially compared to the cost of making and applying charged biochar.

Normally, SA would be applied once per growing season, most likely at the beginning. But, because it can act quickly, it could also be applied to address particular challenges that may arise during the growing season.

Salicylic Acid Works with Various Fertilization Strategies

Looking at the various research papers that include both SA and biochar, the scientists used a variety of ways to inoculate the biochar. See the Appendix in the attachment to this paper for details.

For example, in the first research paper with fig trees in a semi-arid climate, “The full B2 [biochar plus organic inoculants] treatment consisted of 10kg biochar + 500g mycorrhizal fungi + 250mL each of bacterial inoculants (500mL total), plus 100mL fulvic acid and amino acids per tree.”

In the second research paper, also on semi-arid land, the researchers treated triticale with biochar made from cotton, wheat, or sesame agricultural waste. They also used a chemical fertilizer, P, instead of biochar in one of the trials. The biochars in all of the trials were not inoculated. Still the yields were significantly better in every trial with the SA than in those without it.

Based on its wide use, at least in drought prone Asian countries like India and Iran, and on numerous peer reviewed research papers, it appears that SA and biochar work well with any number of organic or chemical fertilizers, or combinations of the two. In research paper #2 above, the biochar was not inoculated at all, yet still achieved excellent results.

The Many Ways SA Increases Farmers’ Incomes, Reduces Their Costs, and Improves the Environment

Because SA is a unique low cost plant hormone that acts *inside* the plant, but can be applied *externally*, it works in ways that complement other crop improvement methods. It’s fast results are also unique and very valuable. Consider the following benefits:

- SA, by itself or in combination with biochar, significantly increases crop yields, plus fruit, nut, and vegetable size, taste, nutrient content and many other plant metrics.
- SA significantly reduces farmers’ costs for buying and applying chemical fertilizers and reduces their environmental damage.

- SA significantly reduces farmers' costs for buying and applying chemical pesticides and reduces their environmental damage.
- SA reduces the soil compaction associated with applying chemical fertilizers and pesticides.
- SA reduces farmers needs for buying and pumping scarce irrigation water, along with the environmental degradation that it causes, e.g., further lowering already low nearby surface waters and aquifers.
- SA's fast action makes it ideal for countering sudden and immediate stressors, such as heat waves, extended drought, and pest attacks.
- SA improves the environment because it reduces the need for chemical fertilizers which produce runoff that contaminates rivers, ponds, and lakes and causes toxic algal blooms that can poison drinking water..
- Since about 70% of surface water is used by agriculture, more water will be left for urban dwellers and industrial uses.
- The cost of testing any of these claims in the field or in a greenhouse is low, since SA is inexpensive to buy, then to highly dilute, and to apply.

How SA Helps Biochar Suppliers Increase Sales and Profits

- Biochar suppliers have many customers who already have biochar on their farms and orchards. Testing a few different foliar concentrations of SA on a few small plots will require minimal costs for the SA and labor.
- Once the biochar-using farmer sees the SA's results on his or her farm or orchard, he or she will ask to have it applied to the rest of the acres, which will not cost much, but will also show impressive and quick results.
- Farmers trust other farmers and their own eyes. As word spreads that the combination of charged biochar and SA brings fast and impressive results at little more than the cost of the biochar alone, they will want the same.

- Remember that biochar and SA work synergistically—SA from inside the plant and biochar from inside the soil. The results are significantly greater than either one could achieve on its own. $1+1 = 3$. See research paper #1, above in this document for an example of this.
- Farmers will be pleased by the quick results of adding the SA and by their ability to reapply it to counter sudden threats—such as heat waves or pest infestations.

Facing the Facts of Climate Change

They say the first step in solving any problem is to face the facts squarely. The fact is that climate change is the biggest challenge that humanity has ever faced. It's also clear that, as much as many well meaning people are striving to solve it, we need to significantly accelerate the pace of mitigation and adaptation or we will soon be overwhelmed. We've already surpassed the 1.5 degree C threshold in some parts of the world, especially near the poles. Irreversible feedback loops may be close at hand. Our political and economic systems have not yet proven to be up to the task.

Biochar, a natural climate solution, has proven to be by far the most cost-effective tool for removing atmospheric CO₂, while simultaneously providing a multitude of co-benefits. But we need to dramatically accelerate the pace and scale of biochar adaptation, if we are to avoid the worst consequences of climate change.

Fortunately, salicylic acid has been shown to be the perfect partner for biochar. Chronic drought and heat waves are affecting larger and larger portions of the earth's agricultural land. Charged biochar improves soil water holding capacity and its microbes provide plant nutrients.

SA is the plant hormone that is uniquely capable of stimulating the plant's own short *and* longer term resilience to abiotic and biotic stresses, e.g., drought, heat, soil pollutants, like salt and heavy metals, as well as many types of pests.

Biochar often takes more than one season to show results. SA shows results in the first season and can even be used to address sudden

stresses. Biochar, by itself, can be too expensive for many farmers to justify. But, SA is very inexpensive to buy and to apply. Due to their synergistic partnership, (1+1= 3), they can be economically attractive to farmers worldwide.

Next Steps to Rapidly Scale Biochar with Salicylic Acid

The best way, I believe, to quickly scale biochar would be for people who understand biochar, to show progressive farmers in drought prone areas how to conduct their own simple, fast, and inexpensive trials on small plots of their own farms. If this paper is right, they should see impressive results in the first growing season.

Biochar suppliers are best suited for doing this work, because they are already experienced with biochar and have many farmer customers who have already purchased biochar from them, as well as other farmers who are good prospects. Since their customers already use their biochar, all they would need to do to test SA's many benefits would be to apply it to a few small areas of their fields, as a trial. The idea is to test three or four different dilution levels of SA to bracket the "sweet spot" of maximum yield.

The application could be as a foliar or as a minute addition to the irrigation water. For new plantings, they could use it as a seed coating for priming. The cost of the SA itself would be under \$50, since it is already inexpensive and is highly diluted. The labor cost should also be very small — probably less than \$300 per test plot.

Unlike biochar alone, which does not usually show significant results in the first one or two seasons, SA, combined with the existing biochar already in the soil, should show results quickly, as demonstrated by increases in yield, product quality, taste, and resistance to drought, heat, and pests.

With these results, the biochar supplier and the farmer should be able to convince other nearby farmers to buy charged biochar plus SA for their own farms as well, thus greatly expanding the biochar supplier's business and profits.

With the help of experts on how to conduct simple and inexpensive trials on existing farms, I will put together instructions for the biochar suppliers

to use to assist their farmer customers. The suppliers would fill out pre-printed forms with the results and email them back to me for filing and publication on an open source website. The trials could be done on farms or orchards for any crops, located anywhere in the world.

The trial instructions would be easy to understand, as well as quick and inexpensive to implement with the proper guidance. For even faster results, multiple trials could be conducted throughout the year in greenhouses and tunnels. Ideally, the regional biochar bodies, like IBI, USBI, EBI, ANSBIG, plus the Indian and Chinese organizations fostering research, standards, and promotion of biochar would all join in this effort.

Please Let Me Know Your Thoughts

If you've read this far, I thank you for your interest and endurance. I would greatly appreciate hearing your thoughts about what you have read here and any ideas you may have. ***Would you be interested in assisting me in helping to coordinate the start up of trials in various parts of the world?***

According to the abstracts of some of the research reports I have read, charged biochar with salicylic acid is already being used in resource constrained countries, like Iran and India. Further, *Google Scholar* reports "about 605" of its research papers include the words "biochar", "salicylic acid", and "increased yield" in their titles and/or texts. I will continue to research where SA + biochar has been applied and post the results on my LinkedIn page.

As climate change drives global drought and heat to ever greater extremes, I believe salicylic acid plus charged biochar can be a relatively quick, easy, and cost-effective way to massively scale biochar.

If I am right, we can make a major impact on mitigating climate change and insuring food and water security for our fellow human beings over the coming years and centuries. They and future generations will thank us.

If you agree with these ideas, I would appreciate hearing your thoughts and forwarding this to others or posting it on your LinkedIn or other social

media pages with your comments. Please let me know about anything you do to publicize this effort. Everything in this document is open source.

If you prefer to share your thoughts off the record, please call me. I will guarantee you complete anonymity. Let me know if you have any questions. Many thanks in advance.

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Attachment: Appendix