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ASSESSING THE AGRONOMIC AND ECONOMIC VIABILITY OF DISTILLERY SPENT WASH AND BOILER ASH MIXTURES AS SUSTAINABLE FERTILIZERS

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Abstract
A significant by-product of the sugar industry is molasses, which distilleries utilize for alcohol production through fermentation. This process generates 10 to 15 cubic meters of wastewater for every cubic meter of alcohol produced. Common disposal methods for this waste effluent include fertilization, irrigation, composting with bio-waste, combustion, and anaerobic treatment. Rich in organic matter, mineral salts, and essential nutrients, this effluent can be efficiently repurposed as a nutrient source and soil amendment. By adopting these methods, industries can enhance soil fertility while managing waste responsibly, contributing to sustainable agricultural practices. Research studies have demonstrated that the nutrient content (NPK) in distillery sludge makes it suitable for use as a fertilizer. A developed fertilizer combining distillery spent wash (DSW) and boiler ash (BA) was tested on cotton fields, resulting in improved crop growth, higher yields, and reduced costs. This approach enhances nutrient availability and offers a viable alternative to synthetic fertilizers for agricultural productivity. A parametric study was conducted to evaluate the effectiveness of this low-cost method, focusing on the utilization of waste materials like DSW and BA from the alcohol industry as sustainable fertilizers. The findings highlight the potential of these waste-derived fertilizers to improve agricultural outcomes while addressing environmental and economic challenges, paving the way for more sustainable industrial and farming practices.

INTRODUCTION

The alcohol industry generates substantial waste materials due to its manufacturing activities and waste-handling methods. Agricultural-based industries, especially those in food processing, are key contributors to this output, with large volumes of organic waste rich in nutrients [1]. Ethanol distillation results in significant quantities of a waste liquid known as Distillery Spent Wash (DSW). This wastewater is acidic and dark brown. It contains elevated concentrations of impurities and a range of salts, including trace metals. If not properly managed, indiscriminate disposal of DSW can degrade soil and water quality, ultimately affecting groundwater resources [2]. Direct contact with this wastewater can also have harmful, toxic, and adverse effects on marine, terrestrial organisms, and even humans.

Thus, efficient and effective management strategies for distillery wastewater are critically important [3]. The ethanol distillation process, which separates and purifies ethanol from fermented sugarcane, generates substantial wastewater that poses serious environmental and health risks if not handled properly [4]. Distillery wastewater is particularly challenging to manage due to its composition and characteristics, requiring appropriate treatment methods to mitigate its negative effects. Its acidic nature can lead to soil acidification, adversely impacting soil fertility and crop productivity [5]. The deep brown color of the wastewater reveals a high presence of organic substances and pollutants, highlighting the importance of proper treatment before discharge or recycling, Due to these environmental and health risks, it is crucial to implement comprehensive and effective management strategies for distillery wastewater. This includes adopting innovative treatment technologies to eliminate pollutants before discharge or reuse [6].

1.1 Fertilizer Application of Spent Wash

The distillery spent wash (DSW) contains a substantial amount of micronutrients like iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), boron (B), and molybdenum, Along with its abundance of organic carbon, DSW contains essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and sulfur (S), making it a valuable resource for agrarian with ecological usage. Its composition enhances earth fruitfulness with promotes crop development [7]. Alcohol industry waste (DSW), a liquid product from the sugar mills, is composed of both organic and inorganic substances. It is abundant in trace elements such as zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn), along with key macronutrients like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). These nutrients are vital for promoting plant development and boosting crop productivity[13]. Properly applied DSW can greatly enhance enzymatic and microbial activity in the soil, enhance organic carbon content and facilitate better nutrient absorption by plants. Furthermore, it improves soil structure, enhances water retention, increases porosity, and strengthens antioxidant applications [11]. Overall advantages eventually prime for improved photosynthesis, better crop development, with increased crop production. (DSW) is rich in crucial command nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, along with trace elements such as zinc, copper, iron, and manganese. This complex liquid byproduct from the sugar mill contains both organic and inorganic compounds that promote plant development and elevate crop yields when used correctly. Proper application of DSW provides a range of benefits for soil vitality and farming efficiency [22]. Distillery waste enhances soil enzyme and microbial activity, fostering a productive environment for nutrient cycling and the breakdown of organic matter. Additionally, it boosts soil organic carbon levels, water retention capacity, and nutrient availability for plants. These enhancements improve water retention, soil porosity, aggregate stability and antioxidant activity, making crops more resilient and supporting sustainable agricultural practices [23].

1.2 Boiler Ash as a Valuable Resource for Organic Fertilization

Sugar industry waste is generated during the sugar production process. After sugarcane was crumpled, also with liquor removed, that residual tissue, recognized as juice residue, was burnt in boilers to heat the water for power generation such material is called boiler Ash. The resulting ash from bagasse combustion currently has no use and poses a significant environmental challenge [29]. The sugar industry is estimated to produce about 2.0 million tons of ashs yearly, making it a considerable residue stream. Boiler ash, which has the potential to valued reserve, covers vital crop developers showing the carbon-based earth conditioner, it could provide that plant developer for crops, boosting yields and improving soil health [30]. Applying boiler ash to fields enhances soil water retention and aeration, contributing to healthier soil and more sustainable agricultural practices. While currently regarded as waste, boiler ash's potential to boost soil fertility and crop productivity highlights its value for further research and agricultural use [31].

1.3 Optimizing Mix Method

Overall Mix involves the act of uniting two or more components. When a solid is combined with a liquid, it creates a semi-solid state where the particles become closely interlinked. The method by which reagents are combined is critical to the outcome of the final product. Often, mixing spans various spatial and temporal scales, affecting how reactants interact over time [39]. Mixing is the thorough blending of components to achieve uniform distribution and interaction, essential across industries such as chemical production, food processing, and pharmaceuticals. The precise control of mixing parameters is vital for achieving the anticipated creation features [40]. When solid particles combine with a liquid, a semi-solid mixture forms where the particles bind closely together, affecting the mixture's overall characteristics. In food production, for instance, proper blending of ingredients like flour and water is essential to achieving the desired dough texture and consistency. Similarly, how reagents are mixed can greatly impact reaction rates and the final product outcome [41].
The spatial and temporal dimensions of mixing influence the rate at which reactants interact, react, and generate products. In intricate chemical reactions with numerous reactants and intermediates, adjusting mixing parameters is essential for maximizing output and ensuring superior product quality. The efficiency of the mixing process influences multiple aspects of the end product, including particle size consistency, homogeneity, and chemical reactivity. Ensuring efficient mixing involves controlling factors like speed, duration, vessel design, and specific techniques used during the process [42]. Advancements such as computational fluid dynamics modelling and state-of-the-art mixing machinery have allowed industries to improve the precision and effectiveness of their blending operations. These technological advancements allow for more precise control, leading to improved outcomes in various operations [43]. Mixing is an essential process in various sectors, facilitating the even dispersal and interaction of different substances. The manner in which, reagents are combined significantly impacts the traits of the end product, as well as the kinetics of the reaction and its overall efficiency. Consequently, it is important to refine mixing methods to improve the quality and effectiveness of the final products.

RESULTS AND DISCUSSION

The experiment was divided into pots labelled A through F, every representing a distinct mixture proportion of the distillery's residue (DSW) to boiler's ash. These mixtures were represented by the ratios 1:1, 2:1, 3:1, 4:1, 5:1, and 6:1, correspondingly.

1.1. Ratio 1:1 Boiler's Ash and DSW

The data in the 'Section-A' column appears to show an upward trend as time progresses. On the x-axis, changed duration 15day, 30day, 45day, 60day, 75day, and 90day are marked, while the y-axis displays plant growth measurements. The horizontal axis thus represents days elapsed.

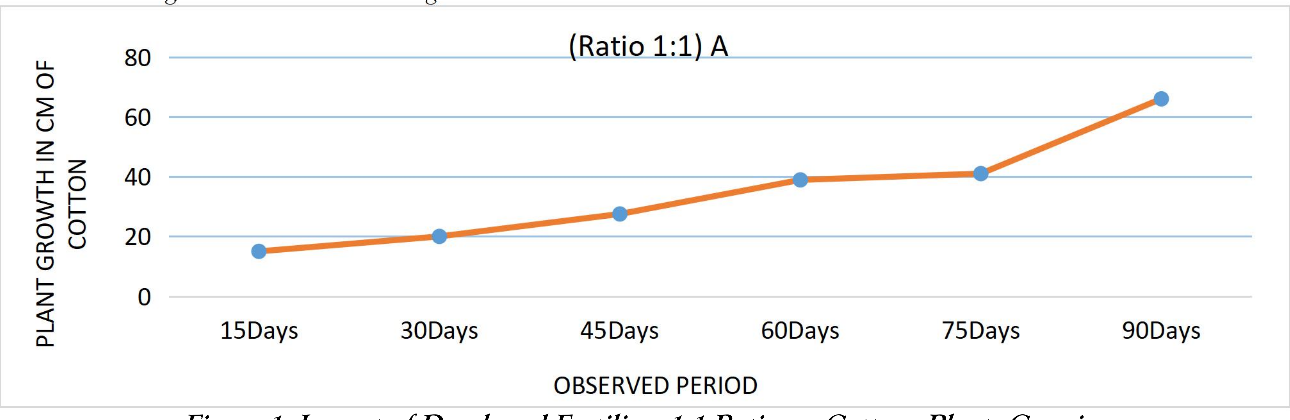

Figure 1: Impact of Developed Fertilizer 1:1 Ratio on Cottons Plants Growing

In 'Section A,' the y-axis shows the recorded heights of cotton plants, measured at 15, 20, 27.5, 38.9, 41, and 66 centimetres. Figure 1, illustrates a general upward trend, with y-axis values rising over time.

This pattern suggests that the application of the developed fertilizer positively influences plant growth.

1.2. Ratio 1:2 Boiler's Ash and DSW

The vertical axis represents plant development, while the horizontal axis displays time intervals in days. The overall pattern indicates a steady rise in plant tallness concluded period, highlighting that the integration of the alcohol industry's residue with boiler ash effectively promotes growth and development. Overall sharpest portion of that arc within Figure 2, highlights that phase of utmost accelerated development, with that plant reaching a significant height of 69 centimetres by 90 days, reflecting substantial development.

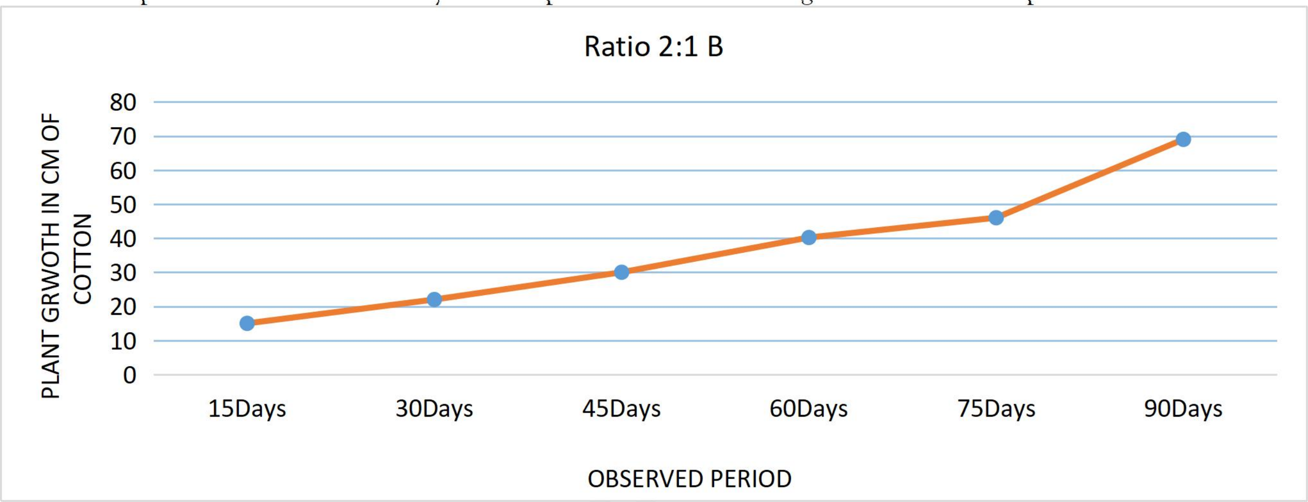

Figure 2: Impact of Developed Fertilizer 2:1 Ratio Cotton Plants Growing

1.3. Ratio 1:3 Boiler's Ash and DSW

The vertical axis indicates plant development, while the horizontal axis marks time intervals in days. The overall pattern reveals a positive trend, containing plants tallness steadily rising concluded 90 days duration. The suggestions were a 3:1 blend of distillery's residue (DSW) with boiler's ashs to supports continuous plant development over time.

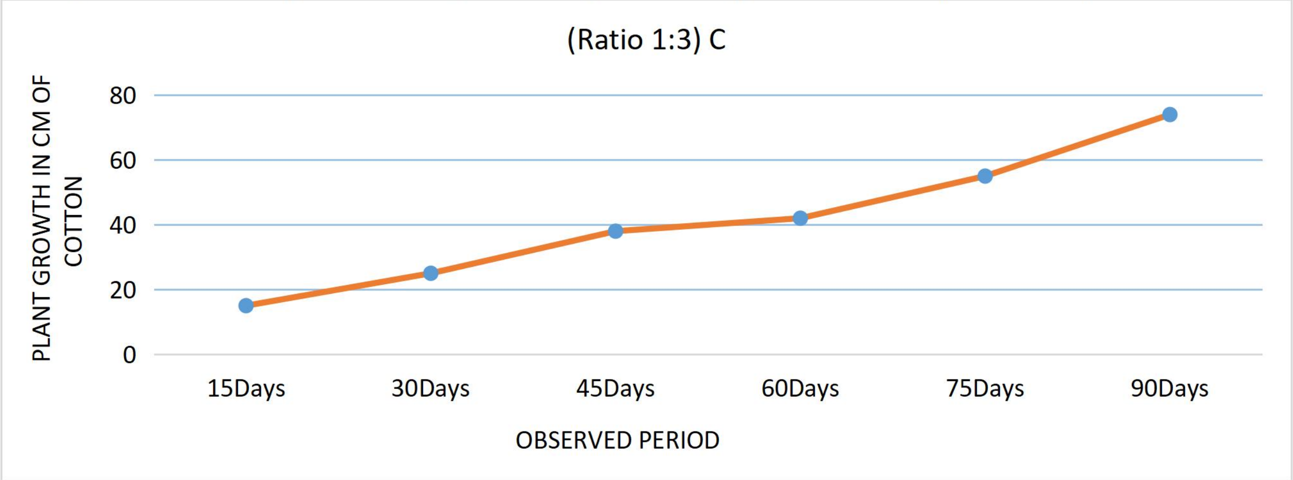

Figure 3: Impact of Developed Fertilizer 1:3 Ratio on Cottons Plants Growing

The growth rate appears to vary, with marked increases from 30 to 45 days and additional important rises from 75 days to 90 days. At the end of 90 days, the plant height reaches 74cm. Figure 3, illustrates considerable development, indicating the particular mixture proportion positively impacts plant development. Comparing this with the 2:1 ratio reveals how varying mixture ratios influence development differently.

1.4. Ratio 1:4 Boiler's Ash and DSW

The vertical axis indicates plant development, while the horizontal axis represents time intervals in days.

The overall trend displays a consistent rise within plants' tallness ended at 90 days duration, suggesting that a 4:1 mix positively impacts growth. Similar to the 3:1 ratio, phases of accelerated growth are noticeable, especially between 30 and 45 days and once more from 75 to 90 days. After 90 days, the cotton plant reaches a height of 85 centimetres, the tallest plants observed among the ratios analyzed. Figure 4, specifies that a 4:1 mix could exert an additional significant optimistic result upon inclusive plant expansion. Associating that development trend with those of the 3:1 and 2:1 ratios provides valuable insights into assessing any notable difference in the effectiveness of these mixtures.

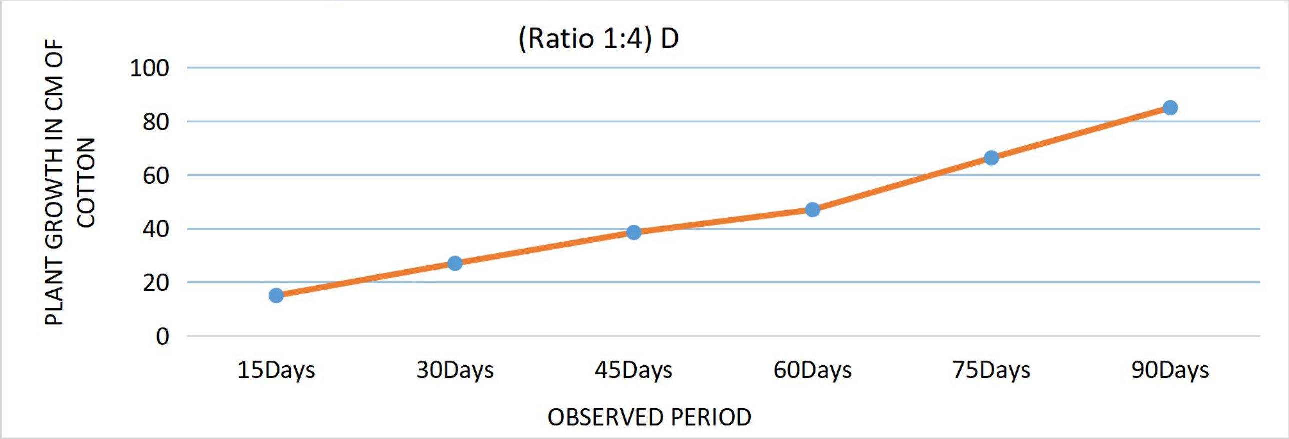

Figure 4: Impact of Developed Fertilizer 1:4 Ratio on Cottons Plants Growing

1.5. Ratio 1:5 Boiler's Ash and DSW

The vertical axis illustrates plant growth, while the horizontal axis marks time in days. Figure 5.5 is expected to show a steady rise in plant height throughout the 90 days, reflecting consistent growth. The noticeable gains in height at each interval contribute to an overall upward trajectory. These findings suggest a positive effect of the 5:1 blend of distillery's residue with boiler's ash on the plant's development across the observed period.

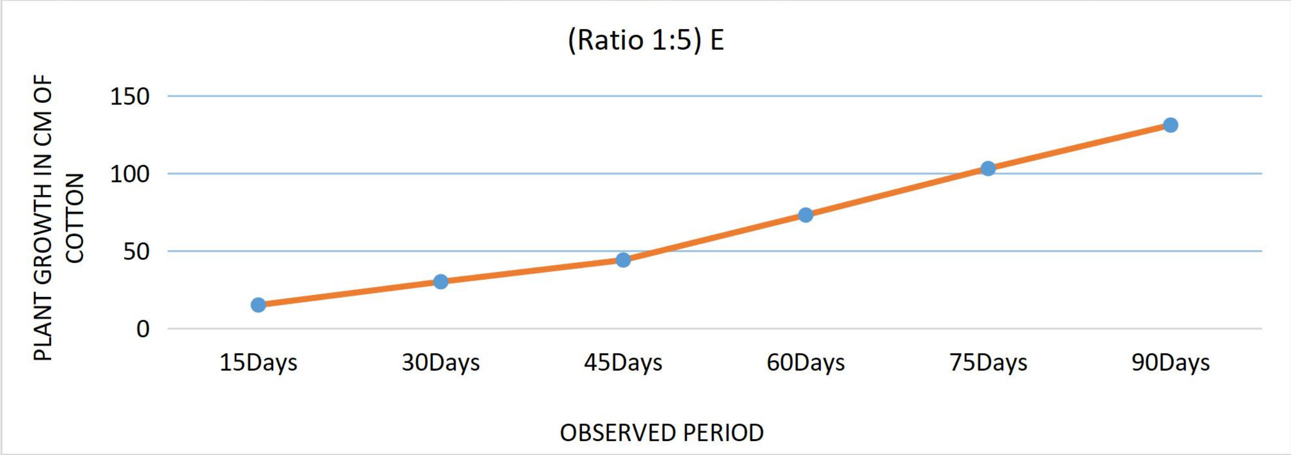

Figure 5: Impact of Developed Fertilizer 1:5 Ratio on Cottons Plants Growing

Plant height shows a consistent increase across all durations, demonstrating the significant positive impact of the 5:1 mixture on expansion. The final recorded tallness of 131cm on 90 days, exposed in Figure 5, stands out as the uppermost among studied proportions, indicating so 5:1 blend is particularly effective in promoting vigorous development. Comparing this growth trend with other ratios (4:1, 3:1, 2:1) reveals distinct patterns and variations in each mixture's effectiveness. The 90-day final height of 131 centimetres notably exceeds the heights achieved with other ratios, emphasizing the superior impact of the 5:1 ratio on promoting plant development.

1.6. Ratio 1:6 Boiler's Ash and DSW

In this section, plant growth is shown on the vertical axis, with time intervals in days on the horizontal axis. The first height of the cotton plant within plot F was recorded at 15 cm after 15 days. Growth continued steadily, reaching 41 cm by day 60, but no further increase was noted between days 60 and 90, as displayed in (Figure 5.6). Growth ceased after 60 days, suggesting a possible negative impact on the cotton plants during this period. The plateau shown in Figure 6, between days 45 and 60 implies the plants may have encountered stress or damage. If the mixture is contributing to these effects, modifying its composition may be necessary to foster a more supportive environment for plant development.

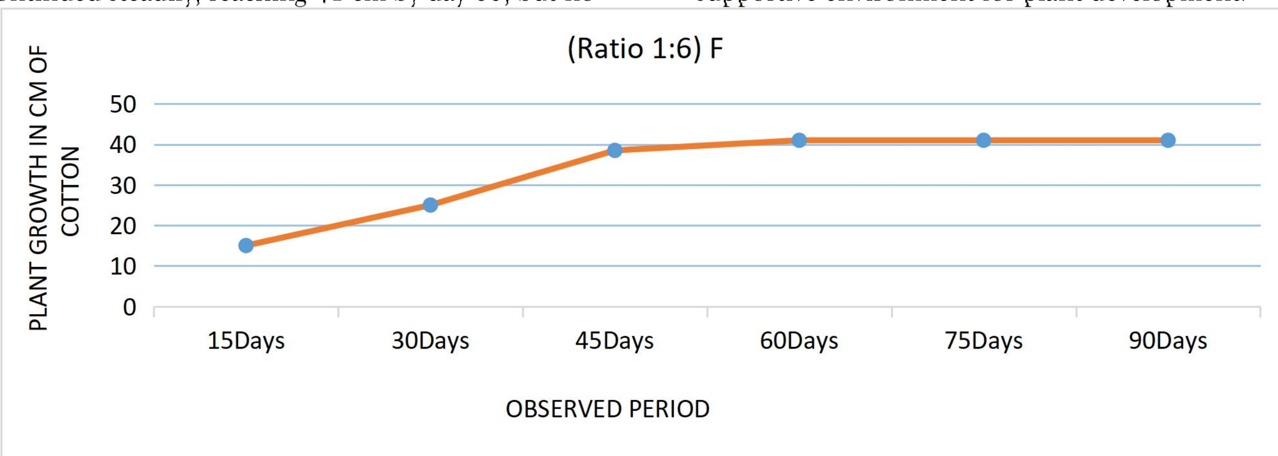

Figure 6: Impact of Developed Fertilizer 1:6 Ratio n Cottons Plants Growing

1.7. Results justification

Examining plant growth data across plots such as plot-A, plot-B, plot-C, plot-D, plot-E, also plot-F each treated to different ratios of distillery's residue (DSW) with boiler's ashs through up to 90day reveals a consistent rise within plants tallness. The steady growth suggests that plants are regularly receiving sufficient nutrients, H_2O, with sunshine to support plant's expansion, as shown in Figure 7.

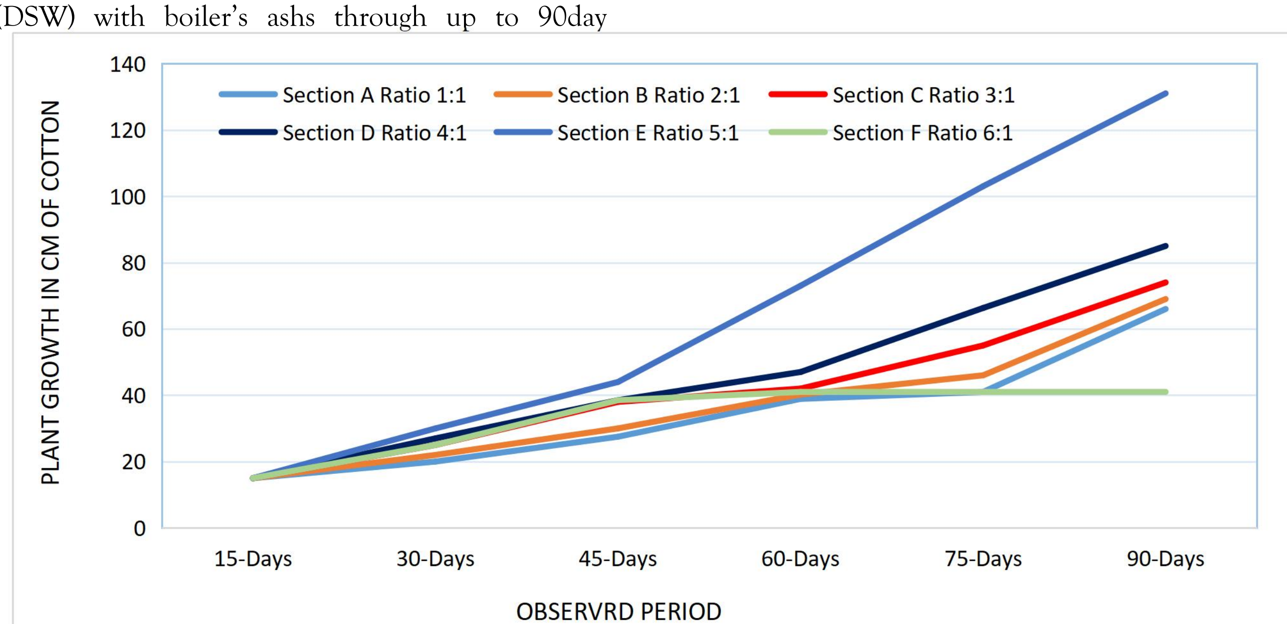

Figure 7: Boiler's Ash and DSW developed Fertilizer applied to Cotton Plants development Results Justification

Figure 7, section A, 1:1 ratio of developed fertilizer shows the plant thriving under favourable growing conditions, with a noticeable growth spurt between 45 and 60 days. During this time, plants appear to undergo rapid development, likely due to factors like sufficient water, nutrient accessibility, and idyllic weather conditions. In Figure 7, section B 2:1 of a developed fertilizer gives the plant development progresses steadily throughout the observation period, with plant height gradually increasing. This consistent upward trend reflects a healthy crop, with no signs of stress or unfavourable conditions affecting growth. This steady progression allows for predictions about future growth stages, aiding in the planning of agricultural practices to maintain plant health and productivity. Figure 7, section C, 3:1 blend of developed fertilizer illustrates a continuous rise in plant height throughout the 90 days, indicating a stable growth environment where plants are efficiently absorbing resources like nutrients, aquatic, and sunshine. The fixed rise of elevation suggests that the plants are in good health and likely to achieve optimal development, making it essential to support this growth trend with appropriate agricultural management. In Figure 7, section D, 4:1 of developed fertilizer shows the plants show uninterrupted growth, A marked increase in plant height is observed between 60 days plus 75 days, indicating faster development stages. This surge may result from optimal environmental conditions, such as improved nutrient absorption and favourable climatic factors during this period. That rapid growth indicates that the plant entered an extremely fruitful phase. Making it important to manage resources effectively to sustain this growth and maximize yield. Figure 7, demonstrates healthy, unceasing development in Section E, 5:1 ratio of developed fertilizer where plant height exceeded additional plots by finish to that observed duration. That 5:1 proportion of distillery's residue with boiler's ash seems to provide ideal circumstances for plant development, by a fixed rise within tallness over 90 days. This mixture provides a balanced supply of nutrients, resulting in robust plant development. Associated with additional proportions, plot-E outstrips particulars, indicating that the 5:1 mixture has superior fertilizer potential for cotton plants. Figure 7, initially shows solid development in Section F, 6:1 of developed fertilizer giving the plants elevation stagnates at 60 days. Through up to the 90-day mark, the plants have deteriorated and died. The 6:1 ratio seems to cause stress after 60 days, halting further growth. This highlights that while other ratios, particularly 5:1, foster better plant development, the 6:1 mixture is not conducive to long-term growth and plant health.

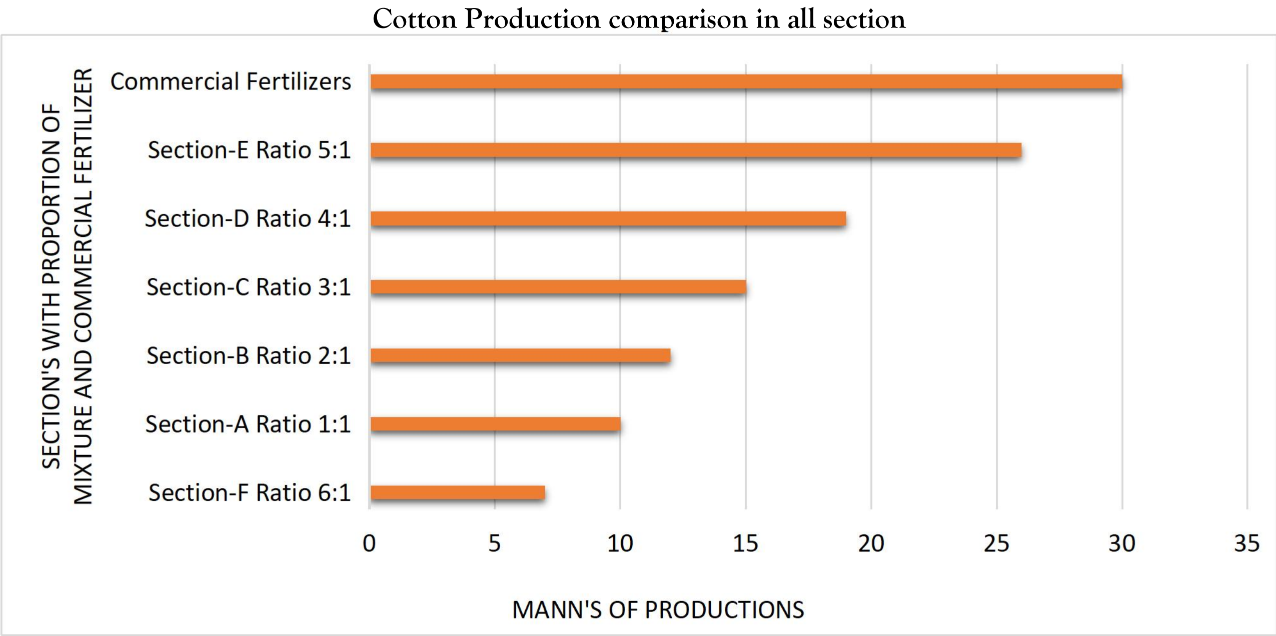

Figure 8: Boiler's Ash and DSW Results Justification as fertilizer.

The combinations of distillery's residue(DSW) and boiler ash were applied in changed proportions (i)1:1, (ii)2:1, (iii)3:1, (iv)4:1, (v)5:1, (vi) 6:1 across Sections A through F, to compare their effectiveness against a standard commercial fertilizer yield. Notably, Section F, which used the 6:1 ratio, produced the lowest yield among all sections, indicating a possible disadvantage associated with this particular mix. (1 Mann, = 40 kg). In Section A, the 1:1 ratio resulted in higher production levels than in Section F (6:1), yet it still fell short compared to the other sections. As illustrated in Figure 5.8, this ratio might not be a maximum ideal for achieving maximum output. Plot B validates additional rise within productions associated with plot A, as depicted in Figure 8. Employing the 2:1 ratio notably boosts output, indicating that this specific mix enhances competence also output within plot- B. That assessment amongst plot-A also plot-B highlights the advantages of adjusting ratios to support growth and yield, emphasizing the role of ratio optimization in agricultural practices. In Section C**,** there is a marked improvement in production, with the 3:1 ratio yielding much better results than the 2:1 ratio shown in Figure 8. This significant enhancement demonstrates the 3:1 ratio's superiority in increasing productivity, suggesting it is more effective for optimizing growth processes. The data clearly show that this ratio leads to higher output, making it a more efficient choice for maximizing production. Section D continues this upward trend, with the 4:1 ratio delivering even better results than the 3:1 ratio, as shown in Figure 8. This consistent increase in production indicates that higher ratios result in progressively greater yields. The 4:1 ratio yields better results than the 3:1, demonstrating that further fine-tuning of ratios can substantially enhance production efficiency. These results emphasize the value of ratio adjustments in achieving optimal performance. In Section E, the 5:1 ratio achieves the uppermost production levels amongst complete plots revealed in Figure 8, aside from them utilizing marketable fertilizer. While marketable fertilizers do produce the greatest yield, they are significantly more costly compared to the waste-based blend applied in Section E. As a result, Section E stands out as the most economical choice for farmers, greatly enhancing profitability over the season. The 5:1 ratio is particularly effective in boosting production while keeping costs low, positioning it as an ideal option for sustainable farming practices.

Economy Comparison

Market fertilizer, usually offered in granular or liquid forms, is readily available in the market, with costs per acre fluctuating based on type, brand, and nutrient composition. These fertilizers incur direct expenses tied to manufacturing and distribution. In contrast, distillery washing a by-product of alcohol production is typically more affordable than commercial fertilizers, as it is a waste product. However, there may be additional expenses for transportation and application. Similarly, boiler ash, produced from industrial combustion, is also a waste product and tends to be cheaper than commercial fertilizers, as depicted in Figure 9. Nonetheless, processing and handling costs may be involved. Although Figures 7 and 8 indicate that distillery spent wash and boiler ash have significant potential as fertilizers, practical factors like cost-effectiveness, ease of preparation, and material availability must be considered. The reasons were crucial in determining the viability of the application that precise proportion within farming applies. Utilizing distillery's residue with boiler's ashs indorses profitability through repurposing industrials by-products, dropping left-over, with mitigating that ecological influence related to discarding of residue. Overall reduced price of distillery residue with boiler ash is striking from a profitable point of view. Through using these by-products, farmers reduce waste and contribute to the circular economy. This cost-saving makes fertilization more affordable, encouraging wider adoption and enhancing farming applications. Overall reduced price by acre made distillery's residue with boiler's ashs reachable for wider variety aimed for agriculturalists, counting that by partial economic funds, encouraging more widespread use in agriculture.

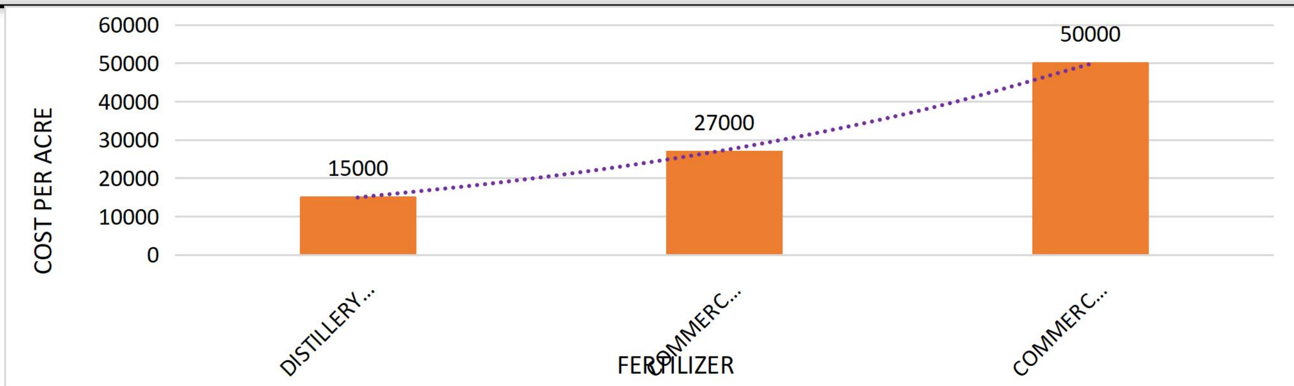

Figure 9: **Commercial Fertilizers with Developed Fertilizer's Acre expenditure**

CONCLUSION

This research assessed how effective various blends of distillery residue with boiler's ashs were form of fertilizer, particularly looking at plant growth, yield, and economic factors. Observations over 90 days revealed unique growth patterns linked to each specific blend ratio. The mixtures in Sections E (5:1) and D (4:1) demonstrated the best outcomes for plant development. Section E displayed vigorous and consistent growth, surpassing the other sections, while Section D maintained stable growth with a significant rise in plant height. On the other hand, Section F (6:1) showed signs of plant stress, deterioration, and ultimately plant death by the 60-day mark, suggesting issues with that particular mixture. Due to the continuous growth observed in Section E (5:1), this mixture emerged as the most promising fertilizer option. It provided ideal conditions for plant development, promoting consistent height increases, which points to a well-balanced nutrient mix. When comparing productivity across different ratios, plot-E (5:1) achieved overall peak yield between the distillery's residue (DSW) with boiler's ashs combinations. Still, commercial fertilizers yielded the highest overall production, even outperforming plot E (5:1). Overall indicates that despite plot-E's effectiveness in boosting growth, marketable fertilizer till chief through standings to absolute output.

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