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Feasibility Studies and Irrigation Design for an Experimental Station in Southwestern Ghana

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***Abstract* – A feasibility studies was conducted at an experimental station of the CSIR-Crops Research Institute to assess its suitability for the development of an irrigation facility earmarked for growing rubber seedlings. An initial reconnaissance survey was conducted after which soil and water samples were obtained for analysis. Results from the water analysis showed iron and turbidity values exceeding the WHO values for guideline. Mean pH ranged from 5.80 to 6.22, while the mean Electrical Conductivity (EC) values ranged from 25.40 to 48.80µS/cm. Total Dissolved Salts values ranged from 16.27 to 31.23mg/l. Total hardness and bicarbonates ranges from 1.60-14.20 mg/l and 6.60-12.70 mg/l respectively. The concentrations ranges for sodium, calcium and magnesium were 1.60-5.00, 1.70-5.20 and 0.20-1.80 mg/l. Soil analysis also showed satisfactory results for all components analysed. The mean pH ranged from 4.36-5.38 with EC also between 2.93 and4.03. Base saturation ranged between 68.66 and 85.26%. Carbon, total nitrogen and organic matter ranged from 0.57-1.41%, 0.04-0.13% and 0.98-2.43 respectively. Sand, clay and silt were in the ranges of 56.00-76-.60%, 8.04-18.04% and 11.40-32.10% respectively for a determined sandy loam texture at a moisture content ranging from 12.4-17.64%.It was recommended that adequate drainage with emphasis on surface drainage should be provided and salt and sodium build-up in the soil and water should be monitored regularly. The physical survey showed an undulating terrain not conducive for drip irrigation, hence a pressurize sprinkler irrigation system was recommended for the station.**

***Keywords* – Feasibility, Irrigation Design, Rubber, Soil Analysis, Water Analysis, Sprinkler Irrigation.**

I. Introduction

The CSIR-Crops Research Institute proposed two flagship projects as part of activities to generate funds. These proposed flagship projects were rubber seedlings establishment and plantain sucker production at its experimental station in the Western Region of Ghana. These rubber seedlings and plantain suckers would be sold to the Ghana Rubber Estates Limited (GREL) on a contractual agreement. Ghana Rubber Estates Limited (GREL) is the largest industrial rubber production company in Ghana, controlling 98 percent of production for the rubber market [1]. Given GREL's limited ability to expand its land resources, it started operating an out grower scheme to provide an alternative way of increasing its supply of raw materials. As part of this project, the CSIR-CRI was invited to produce rubber seedlings for the outgrower schemes supported by GREL. The CSIR-CRI's memorandum of understanding (MOU) with GREL had a bipartite structure: i) financial and resource based (land and labour) investment from the CSIR-CRI and; ii) provision of technical assistance, planting material and final purchasing of rubber seedlings by GREL for onward supply to Rubber Outgrowers' and Agents' Association (ROAA).

Rubber, like other perennial crops, has a long gestation period. During this period returns on investment are lacking and farmers are made to source or plant their food crops elsewhere. As part of GREL's food security program, the CSIR-CRI also proposed intercropping the rubber seedlings (during its establishment phase) with plantain suckers. This would maintain farmers interest and activities in their plantations and in the end give reprieve to farmers in terms of food and alternate income during the long gestation periods of the rubber plant. This objective brought into existence another MOU (with the same bipartite agreement) to produce plantain suckers for GREL's supported ROAA.

An irrigation facility was crucial and warranted for at the station for these proposed projects to be carried out successfully. The proposed irrigation facility is necessary to irrigate rubber seedlings at the nursery until establishment which takes about 7 months and the plantain suckers during production. A feasibility studies was conducted to assess the station's ability to develop and support an irrigation facility in terms of land, soil, water quality and availability. This paper discusses the results from the feasibility studies and gives the necessary recommendations.

II. Methodology

A feasibility survey was conducted to ascertain the suitability of the proposed area for the irrigation project. Existing beacons and other land features were captured during the land survey. These included the buildings, screen houses, access roads, streams/rivers and research fields. Field measurements were taken to aid in the irrigation design. Soil sampling and analysis was done to determine the physico-chemical properties in order to ascertain the soil's suitability for production of the proposed crops. Two streams were identified in the initial survey and sample taken for analysis. Other features such as average velocity and depth were also taken..The average velocity of each stream was determined as described by [2].

Water analysis of the two streams was also conducted using water samples from both upstream and downstream. The samples were labelled as follows: stream A (upstream), stream A (downstream), Tank and stream B. An alternative source or irrigation water was identified as stream B should the results from the water analysis from the first identified source be deemed unsuitable for irrigation. The samples were analysed by the CSIR-Water Research Institute. The chemical parameters that were measured included pH, Electrical Conductivity, Sodium, potassium, Calcium, Magnesium, Total Iron, Ammonia, chloride, sulphate, phosphate, manganese, nitrite, nitrate, fluorides, total alkalinity, carbonates and bicarbonates. The physical components measured were total hardness, turbidity, colour and odour.Initial soil samples were taken at three locations across the entire field at depths of 15 and 30cm for physico-chemical analysis.

III. Results and Discussions

This section discusses the data gathered from the field survey, soil and water analyses and gives design specifications for the proposed irrigation system.

Reconnaissance Survey

CSIR-Crops Research Institute (Aiyinasi Station) is one of the outstations of the CSIR-Crops Research Institute (CSIR-CRI). The outstation is situated in the Western Region of Ghana in the high rain forest zone with a mean annual rainfall of about 2000 mm. The experimental station is located on Latitude 5° 03’ N and Longitude 2° 29’ W and 1km away from the main town of Aiyinasi.

Rainfall in the area is bi-modal with the major rains occurring between March and July and the minor occurring between September and December. The average temperature is about 29°C. The topography of the area is undulating with gentle slopes. The average elevation is 47 m above sea level as corroborated by GPS readings. The station however, had no topographic maps and as part of the recommendations of this study, a topographic map should be drawn to detail out all effects of the area. The rocks are made up mainly of the Cambrian type of the Birimean formation and the Tarkwaian sandstone-Association Quartzite and Phyllites types with economic minerals such as kaolin, silica and gold, as well as sandstone deposits [3].

Soils of the area are of the Nuba series, classified under the Haplicferrasols with tertiary coastal sands forming the parent material [4]. The soils are moderately well drained sandy loam topsoil, underlain by sandy loam to sandy clay loam in the subsoil. The dominant crops are tree crops which include rubber, coconut, oil palm, cocoa and citrus. Food crops produced also include cassava, plantain, cocoyam, rice and vegetables such as tomato, pepper and garden eggs.

Due to the high rainfall regime of the area, Aiyinasi is well endowed with lots of water bodies most of which drains into the sea at the coastal areas of the Western Region. Two streams were identified in the initial survey as potential water sources: stream A (*Mangben* river) had a flow rate of 1.3l/s at an average depth of 0.4m and stream B also with a flow rate of 1.4l/s at 4m. Upon an interview with a long serving staff of the experimental station, stream B (flowing about 500m from the irrigable fields) was found to be ephemeral and only flows for a few weeks during the wet season. The *Mangben* river flows into a constructed tank (with spillway) about 375 m from the proposed irrigable fields and was known to flow incessantly, although with a reduced velocity and capacity during the dry season.

Water analysis

Water from various sources may be of an unsuitable quality for its intended use for irrigation.Conducting water quality analysis gives the opportunity to identify and correct water quality problems that may affect on-farm use and productivity.

The pH represents the degree of acidity (or alkalinity) of the sample. A pH less than 7.0 is acidic, 7.0 is neutral and above 7.0 is alkaline. According to [5],soil pH influences the solubility of nutrients, affects the activity of micro-organisms responsible for breaking down organic matter and most chemical transformations in the soil thus affects the availability of several plant nutrients. From the results (Table I), stream A had a pH range of 5.8 – 6.15.This is good for rubber production which thrives in a soil pH range of 4.5 – 6.5 with the ideal being 5.5 [6].According to [7] a water pH range of 5.5 – 7.0 provides the best conditions for irrigation. This is because water in this pH range maintains nutrient balance, prevents scale formation in irrigation equipment and provides effective chemical disinfection.However only water from stream A upstream flows into the tank, hence the higher pH value of 6.15 can be disregarded since it represents water flowing downstream.Among the components of water alkalinity, bicarbonates are normally the most significant concern. It becomes an increasing concern as the water increase from a pH of 7.4 to 9.3 [8]. Its presence in irrigation water in high levels would precipitate with calcium when the soil is dry, impeding water infiltration and increasing runoff.

According to [9], high levels of bicarbonate can also lead to the development of thin surface crusts on leaves when irrigated with overhead sprinklers and similar crusts on roots which can be damaging to certain plants or field crops. Bicarbonates are also toxic to roots and reduce shoot growth, reduce uptake of phosphorus and many of the micronutrients. Bicarbonates levels in the samples tested ranged from 6.60-12.70mg/l (as shown in Table I) which is quite good according to Spectrum Analytic Inc (n.d) which states bicarbonate levels above 3.3 me/l (200ppm) will cause lime (calcium and magnesium carbonate) to be deposited on foliage when irrigated with overhead sprinklers.According to [7], water that contains high levels of calcium or magnesium salts or both are described as being hard. Other cations such as manganese,

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iron, aluminum and zinc can also contribute to hardness. Hardness does not affect plants directly, but hardness caused by bicarbonates can affect soils, thus having an indirect impact on plant growth. Testing for hardness of water can determine the compatibility of fertilizer and pesticides with irrigation water for chemigation. Some tests may also provide information about possible corrosion problems with equipment [10]. Hardness of the samples tested ranged from 1.6 -14.2 mg/l, a range conducive for all on farm applications as determined by [7]. The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (ECw). EC measures salinity from all the ions dissolved in a sample. This includes negatively charged ions (eg cl-, No3-) and positively charged ions (egca++, Na+). The higher the conductivity of a solution, the greater is its salt content. Table II shows the EC and TDS content of the water sample. For irrigation purposes, EC should be less than 0.7dS/m whereas the TDS should not exceed 450mg/l (FAO guidelines).

The results from the samples showed values less than this. The most common measure to assess sodicity in water and soil is called sodium adsorption ratio (SAR). The SAR defines sodicity in terms of the relative concentration of sodium compared to the sum of calcium and magnesium ions in a sample. The SAR assesses the potential for infiltration problems due to a sodium imbalance in irrigation water. The main problem with a high sodium concentration is its effect on the physical properties of soil. The higher values of the various values of the cations for the tank may be attributed to sediment accumulation

Table I: Mean Values for pH, Total Alkalinity, Carbonates, Bicarbonates and Total Hardness

Sample ID	pH	Total Alkalinity mg/l	Carbonates, mg/l	Bicarbonates, mg/l	Total hardness, mg/l
Stream A upstream	5.8	8.40	0.00	10.2	14.2
Tank	5.9	10.40	0.00	12.7	1.6
Stream A downstream	6.15	5.8	0.00	7.10	12.2
Stream B	6.22	5.4	0.00	6.60	5.0

Table II: Electrical Conductivity (EC) and Total Dissolved Salts (TDS)

Sample ID	ECwuS/cm	ECwdS/m	TDS mg/l
Stream A upstream	48.8	0.0488	31.23
Dam	38.1	0.0381	24.384
Stream A downstream	30.0	0.03	19.20
Stream B	25.4	0.025	16.256

Table III: Cations and Sodium Adsorption Ratio (SAR)

Sample ID	Na+ mg/l	Na + meq/l	Ca++ mg/l	Ca ++ meq/l	Mg++ mg/l	Mg++ meq/l	SAR
Stream A upstream	3.60	0.1565	5.20	0.13	0.30	0.0123	0.5868
Tank	5.00	0.2174	3.50	0.0875	0.70	0.0288	0.9017
Stream A downstream	2.00	0.0869	1.80	0.0450	1.80	0.0741	0.3565
Stream B	1.60	0.0696	1.70	0.0425	0.20	0.0082	0.4372

Table IV Guidelines for Assessment of Sodium Hazard of Irrigation Water Based on ECw and SAR

Sodium Adsorption Ratio (SAR)	Potential for infiltration problem	
	Unlikely	Likely
0-3	>0.7	<0.2
3-6	>1.2	<0.4
6-12	>1.9	<0.5
12-20	>2.9	<1.0
20-40	>5.0	<3.0

Source: [11]

Many factors including soil texture, organic matter, cropping system, irrigation system and management affect how sodium in irrigation water affects soils. Soils most likely to show reduced infiltration and crusting from water with elevated SAR (greater than 6) are those containing more than 30% expansive clay. [11]developed guidelines for assessing sodium hazard of irrigation water based on EC_w (Table II) and SAR as shown in Table III. From Table IV,the likelihood of experiencing any infiltration problems or crusting from prolonged use of the water from either stream is negligible.

Chlorides in irrigation water contribute to salinity and when concentrations are high, can be toxic to plant and inhibit growth [11]. Overhead irrigation water high in chlorine can cause leaf burn or leaf drop especially when the rate of evaporation is high. From the analysis, the level of chloride (Table V) of both streams would not pose any eventual problems if used for irrigation. Irrigation water with iron levels above 0.1ppm (equivalent to 0.1mg/l) may cause clogging of drip irrigation emitters whilst levels above 0.3ppm may also lead to iron rust stains and discoloration on plant foliage in overhead irrigation applications [12].

The maximum total iron value from the samples taken was 1.59mg/l which was observed for the tank (Table V). This could imply that there was iron buildup in the tank's stagnant water hence this high value. However, this concentration level does not pose any serious threat to crops. Regular water analysis would be conducted to verify the total iron content of the irrigation water.

Table V: Chemical Properties of Sample

Sample ID	Total Iron mg/l	Flouride, Mg/l	Ammonia Mg/l	Chloride Mg/l	Sulphate Mg/l	Phosphate mg/l	Manganese Mg/l
Stream A upstream	1.2	<0.005	<0.001	6.0	5.3	0.040	0.414
Tank	1.59	<0.005	<0.001	4.0	6.4	0.153	0.400
Stream A downstream	0.114	<0.005	<0.001	4.0	4.4	0.148	0.110
Stream B	0.815	<0.005	<0.001	4.0	4.1	0.279	0.114

Table VI: Ammonium, Nitrites and Nitrates

Sample ID	Ammonia (NH_4N) mg/l	Nitrite (NO_2^-N) mg/l	Nitrate (NO_3^-N) mg/l
Stream A upstream	<0.001	0.011	0.107
Tank	1.59	0.018	0.167
Stream A upstream	<0.001	0.025	0.162
Stream B	<0.001	0.014	0.151

The most readily available forms of nitrogen are nitrates and ammonium but nitrate (NO_3^-N) occurs most frequently in irrigation water [13]. Table 6 gives ammonium, nitrites and nitrate ranges between 0.001-1.59, 0.011-0.025 and 0.107-0.167mg/l respectively with the highest values recorded for the tank. Since nitrogen is present in so many water supplies, it is recommended that the nitrogen content of all irrigation water be monitored and the nitrogen present included as an integral part of the planned fertilization programme [13].

Turbidity is often described as a general term to describe the lack of transparency or cloudiness of water due to the presence of suspended and colloidal materials such as clay, silt, finely divided organic and inorganic matter, plankton and microscopic organisms. According to [12], highly turbid water may also not be suitable for agricultural micro-sprinkler irrigation because of the likelihood of quickly clogging filters, tubing and emitter. From Table 7, turbidity values ranged from 3.2-51.1 NTU whilst total suspended solids and total dissolved solids values ranged from <0.10-25 and 14-26.8mg/l respectively with an inoffensive odour for all samples.

Soil Analysis

According to [14], the properties of a soil which determine growth of rubber plants are those which influence the extent of root proliferation, air and water movement and availability of water. Thus the soil sample which was found to be a sandy loam at moisture content ranging from 12.40-17.64% was deemed suitable for rubber production. [15]also identifies that maintaining proper soil pH is one of the most important aspects of soilfertility management.

Table VII: Physical Characteristic of Water Samples

Sample ID	Colour, Hz	Turbidity, NTU	Total suspended solids mg/l	Total dissolved solids, mg/l	Odour
Stream A upstream	10.0	31.6	25.0	26.8	Inoffensive
Tank	10.0	14.5	1.0	21.0	Inoffensive
Stream A downstream	1.0	3.20	<1.0	16.5	Inoffensive
Stream B	20.0	51.1	16.0	14.0	Inoffensive

Table VIII: Soil Texture, Moisture Content, Electrical Conductivity, Base Saturation and Available Brays

Sample ID	% Sand	% Clay	% Silt	Texture	M.C %	E.C.E.C cmol/kg	% Base saturation	Available Bray's	
								ppmP	ppmK
Site A 0-15 cm	58.46	14.02	27.52	Sandy loam	14.92	3.05	85.26	14.59	11.55
Site A 15-30 cm	56.00	18.04	25.96	Sandy loam	12.40	2.93	84.64	5.98	9.38
Site B 0-15 cm	76.60	12.00	11.40	Sandy loam	13.88	3.61	72.31	1.67	11.19
Site B 15-30 cm	59.89	8.04	32.10	Sandy loam	12.44	4.03	70.21	2.71	13.35
Site C 0-15 cm	68.86	10.04	21.10	Sandy loam	15.48	3.32	69.90	0.64	9.38
Site C 15-30 cm	66.57	14.02	1941	Sandy loam	17.64	3.19	68.66	0.24	9.74

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Table IX: Soil pH, Percentages of Carbon, Total Nitrogen, Organic Matter and Exchangeable Cation

Sample ID	pH 1:1 H_20	% Carbon	% Total Nitrogen	% Organic Matter	Exchangeable Cationcmol/kg Ca	Mg	K	Na	T. E. B cmol/kg	Exch. A (AI+H) cmol/kg
Site A 0-15 cm	5.38	0.92	0.11	1.59	1.34	0.80	0.32	0.15	2.60	0.45
Site A 15-30 cm	5.24	0.74	0.08	1.28	1.34	0.53	0.42	0.19	2.48	0.45
Site B 0-15 cm	4.63	1.41	0.13	2.43	1.34	0.53	0.51	0.23	2.61	1.00
Site B 15-30 cm	4.43	1.41	0.13	2.43	1.07	1.07	0.49	0.20	2.83	1.20
Site C 0-15 cm	4.56	1.28	0.11	2.21	1.07	0.53	0.51	0.22	2.32	1.00
Site C 15-30 cm	4.50	0.57	0.04	0.98	1.07	0.53	0.42	0.17	2.19	1.00

When soil pH is maintained at the proper level, plant nutrient availability is optimized, solubility of toxic elements is minimized, and beneficial soil organisms are most active. Soil pH ranged between 4.50 and 5.38. Percentages of carbon, total nitrogen and organic matter were in the ranges of 0.57-1.41, 0.04-0.13 and 0.98-2.43 respectively (Table VIII).

Exchangeable cations (cmol/kg) for calcium, magnesium, potassium and sodium ranged from 1.07-1.34, 0.53-1.07, 0.32-0.51 and 0.15-0.23 respectively (Table IX).

Irrigation Design

After assessing the lands suitability for irrigation, a design was made for a sprinkler irrigation system.Due to the undulating nature of the area, a sprinkler irrigation system was chosen to be the best method. Even though most irrigators advocates for drip irrigation as a means of water conservation, choosing the sprinkler irrigation system would save the exorbitant cost of leveling (the undulating research lands of the station)associated with drip irrigation system. The system is designed to have features as shown in Figure I.

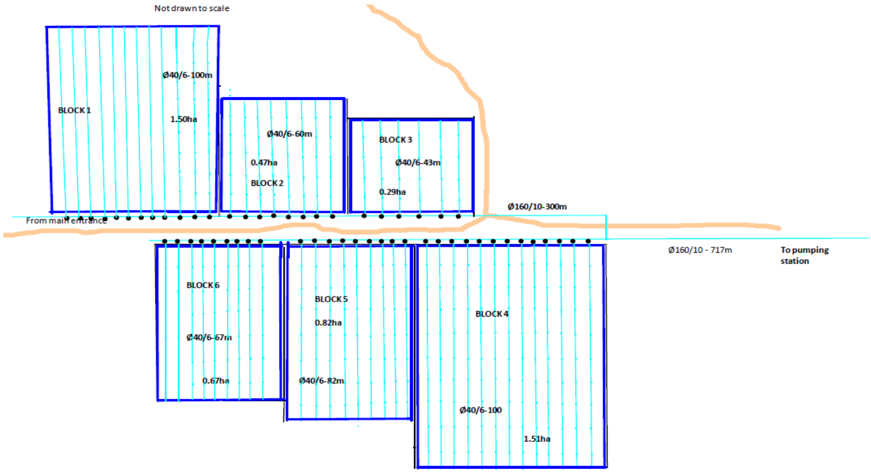

Fig.I. Sprinkler Irrigation Design for Aiyinase Station (not drawn to scale)

Table X: Details for the various blocks in the design

Block no.	**Area, ha**	**No. of laterals and valves**	**Total length of laterals, m**	**No. of sprinklers**
1	1.50	12	1200	108
2	0.47	8	480	40
3	0.29	6	258	24
4	1.51	13	1300	117
5	0.82	9	738	63
6	0.67	9	603	54
Total	**5.26**	**57**	**4579**	**406**

To enable water conveyance to the fields, a pumping station would be installed. This would include a 40HP electric pump with delivery diameter of 160mm, discharge of $60m^3/h$ and a dynamic head of 50 m. The pumping station shall include foot valves, flow meters, pressure gauge and regulators, valves and filters. With a pump discharge of about $60m^3/h$ operating for 4 hours per day, the tank should be expanded to hold an average of $2000m^3$ of water for irrigation purposes. The reservoir capacity was based on two factors: i) the perennial abilities of the *Mangben* River as it flows incessantly throughout the year (but with reduced capacity during the dry season) and ii) the average velocity of the river (up to 20 m upstream from the tank) which was found to be 1.3l/s for an average depth of 0.6m.

With a rated pumphead of 50 m, it is recommended that a larger diameter pipe is chosen in order to gain by lowering the head loss due to friction. The main pipeline would therefore consist of polyethylene(PE)pipes of diameter 160mm conveying water from the pumping station to the fields. At about 375m infield from the water source, a hydrant is designed with connectors and valves to divert the water distribution to the two distinct parts of the fields as detailed in the Fig I.

The lateralsare designed to consist of 40mm diameter PE pipes connected to hydrants spaced 12m apart on the main pipelines. The total irrigablefield was also divided into 6 blocks for ease of installation and operation. The laterals are also laid 12m apart on the main pipeline. Each lateral is connected to a valve for ease of operation; to help turn on and off the flow of irrigation water in the main conveyance pipes.

The sprinklers would be medium pressure, twin nozzle sprinklers, with nozzle size of 3.5 x 2.5 mm. operating with a flow rate of 1.2m^3/h and a swath radius of 12m (resulting in 24m coverage). The sprinklers are laid in-line at 12 meters apart on the laterals. These laterals are also laid 12m apart thereby giving the sprinkler a definite square arrangement of 12m x 12m for effective field coverage and proper circular irrigation patterns. The spacing from the edge of the field for the first sprinkler is 6 meters on each lateral. The sprinkler specification is as shown in Table XI.

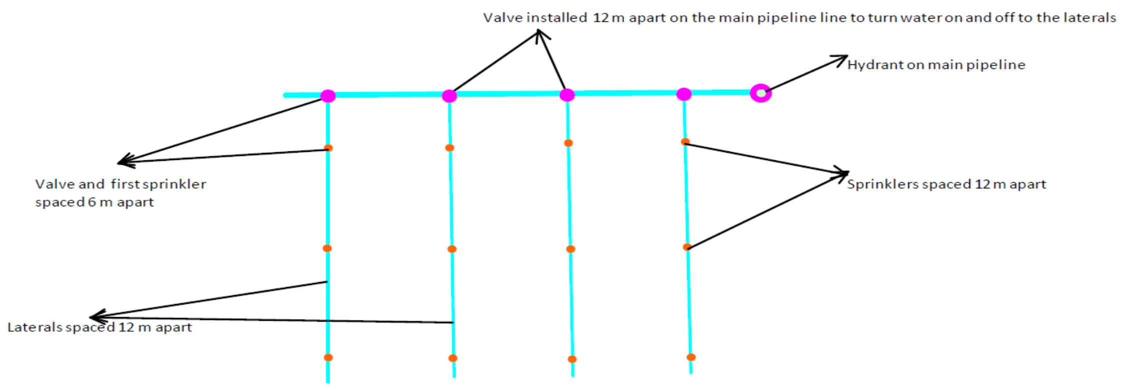

Fig.II. Schematic layout of sprinkler systems

Table XI: Sprinkler specifications

Description	Unit	Value
Lateral spacing	M	12
Sprinkler spacing	M	12
Application rate	mm/h	3.8
Sprinkler discharge	l/h	540
sprinkler working pressure	M	30

IV. Conclusion and Recommendation

A preliminary study has found the area suitable for the set-up of an irrigation system.Most of the water quality parameters tested within the FAO standards for irrigation. Iron, turbidity and colour values exceeded WHO guideline values.Results from the soil analysis were quite appropriate for supplementary irrigation with each meeting the FAO standards.Recommendations are being made to set up a sprinkler irrigation system to cover an initial area of 5 ha which would be expanded further with the development of the rubber seedlings production project in the near future. With this expansion in mind, a solid set irrigation system has been designed to cater for 5 ha but has the potential to serve an area of about 20 ha under future expansions. It is also recommended that adequate drainage with emphasis on surface drainage should be provided. Salts and sodium build up in the soil and water should also be monitored regularly.

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