Student Worksheets

Climate Smart Cocoa Production

Name: _____

Overview:

1) Entry into the teaching unit

Notes:

2) Cocoa Plants
O) Preparatory Homework

Task: Ask someone who owns / manages a cocoa farm the following two questions:

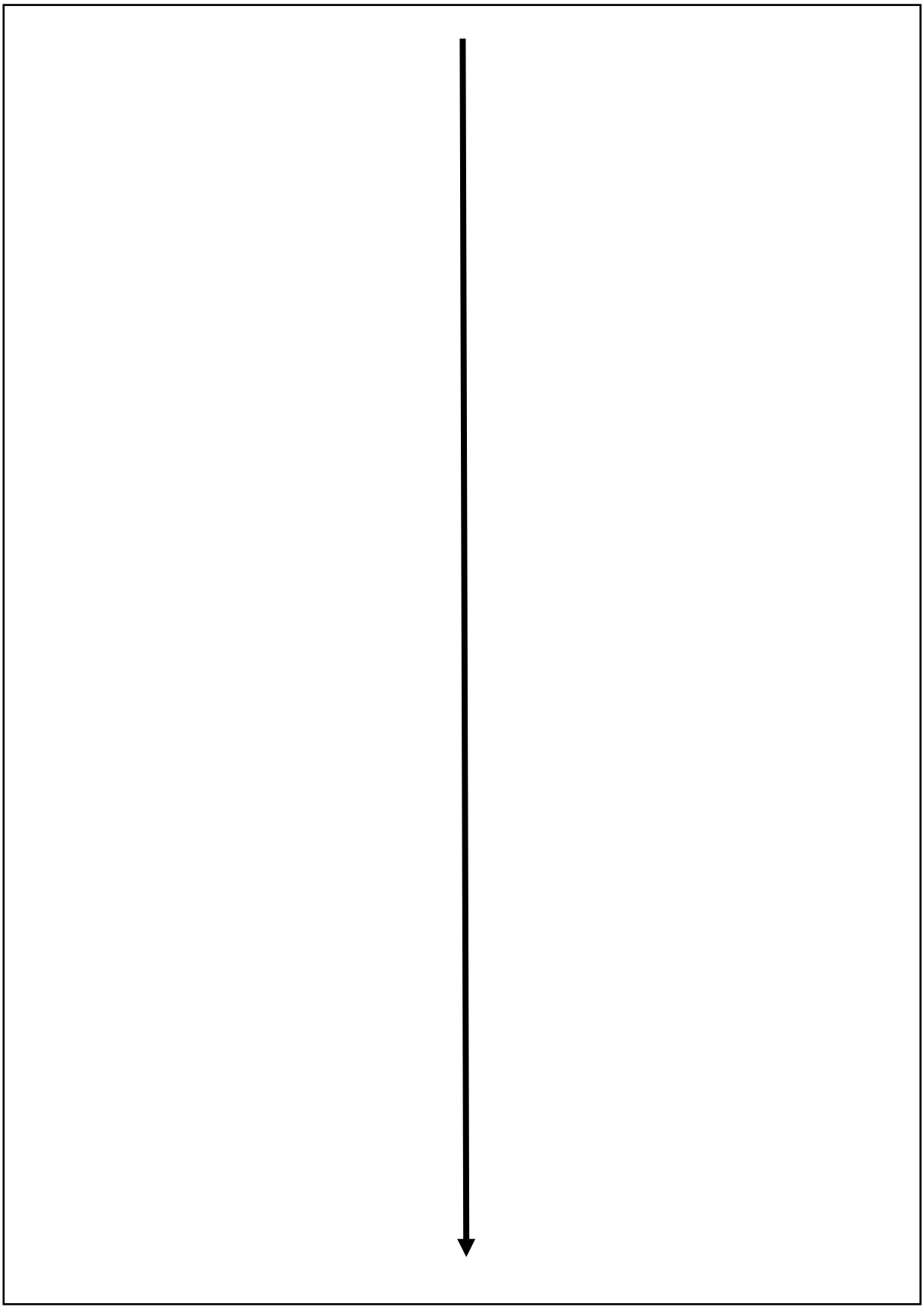
A) What does the cocoa tree need to grow well?

Notes:

B) What are the pests and diseases of the cocoa tree?

Notes:

2) Cocoa Plants
A) History of cocoa tree



2) Cocoa Plants
B) Botanical Characteristics

Task:

a) Draw a sketch of a cocoa tree.

b) Name the parts of the plant.

c) Fill out the profile below.

Jorquette = The point at which the vertical stem forks to produce horizontal shoots
Choupon = Vertically growing shoots

Name: _____ Scientific Name: _____

Family: _____

Height: _____

Roots: _____
_____

Leaf: _____
_____

Flowers: _____
_____

Fruit: _____
_____
_____

Pollination: _____
_____
_____

2) Cocoa Plants
C) Ecology and cocoa cultivation

Task 1: Discuss the findings of the preparatory homework in class and complete your notes on the homework sheet *O) Preparatory homework*.

Task 2: Read the following text and summarize the growth conditions of the cocoa tree in the relevant boxes.

Cocoa grows best in a warm and humid environment. The temperature in cocoa-growing areas usually ranges from a maximum of 30°-32°C to a minimum of 18°-21°C, the ideal mean temperature being 26°C. Rainfall should be plentiful and well distributed throughout the year. An annual rainfall level of between 1,500mm and 2,000mm is generally preferred. Trees are very sensitive to a soil water deficiency. Dry spells, where rainfall is less than 100mm per month, should not exceed 3-4 months.
The cocoa tree will make optimum use of any light available and traditionally has been grown under shade. Its natural environment is the Amazonian forest which provides natural shade-trees. Shading is indispensable in a cocoa tree's early years – it protects the young trees from wind and helps to produce a tree structure suitable for cropping lager on. Cocoa needs a soil containing coarse particles and with a reasonable quantity of nutrients, to a depth of 1.5m to allow the development of a good root system. Below that level it is desirable to have permeable material, so that excess water can drain away. Cocoa will withstand waterlogging for short periods, but excess water should not linger. The cocoa tree is sensitive to a lack of water, so the soil must have both water retention properties and good drainage. Soil types best suited for cocoa are clay-loams, loams, and sandy loams in the pH range of 5.0-7.5. The soil should also have a high content of organic matter: 3.5% in the top 15 centimetres of soil.[1]

Temperature

Soil

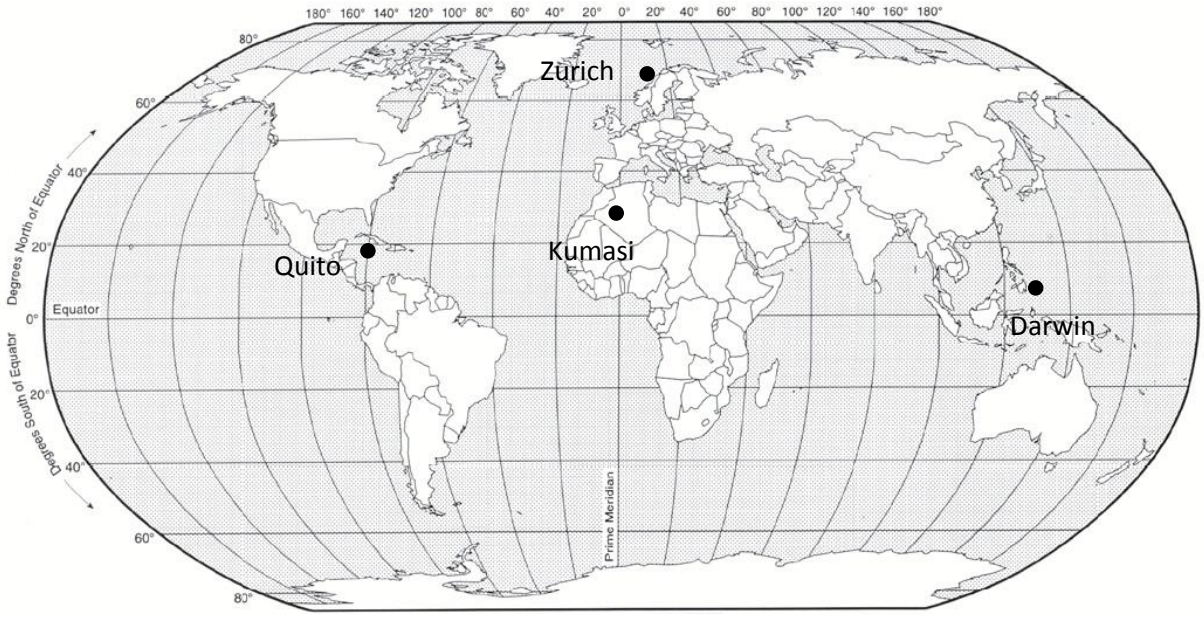
Rain

Light

[1] https://www.icco.org/about-cocoa/growing-cocoa.html

Task 3: The world's largest producers of cocoa are: Ivory Coast, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador, Mexico, Peru, Dominican Republic, Togo, Papua New Guinea, Colombia.

a) Colour these countries on the world map. Look at the latitudes. What do you notice?



b) In which climate zone are the marked countries?

Task 4: Compare the growing conditions of the cocoa tree (see Task 2) with the climate data of Kumasi, Zurich, Quito and Darwin (see table). Where can cocoa be grown and where not? Justify your decision.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kumasi (GHA)	Mean T (°C)	26.5	27.6	27.9	27.4	27.3	25.8	24.7	24.4	25.4	26	26.8	25.7
	Rain (mm)	8	63	136	150	176	216	133	79	169	190	86	32
Zurich (CH)	Mean T (°C)	0.2	1.7	5.1	8.7	12.9	16.3	18.4	17.6	14.9	10.2	4.7	1.3
	Rain (mm)	5	68	68	89	105	129	119	132	90	68	80	72
Quito (ECU)	Mean T (°C)	14	14	14	13.9	14.1	13.6	13.7	13.8	13.9	14	13.8	14
	Rain (mm)	120	137	163	189	116	56	22	32	84	130	120	104
Darwin (AUS)	Mean T (°C)	28.2	27.9	28.1	28.1	26.7	24.8	24.4	25.6	27.7	29.1	29.2	28.8
	Rain (mm)	426	359	335	86	15	2	1	4	18	76	121	251

Task 5: Check out the two main cultivation methods of cocoa.

Monoculture

Only cocoa trees are planted using this cultivation method. The trees are very narrow (up to 1,600 trees per hectare at a distance of 2.5m x 2.5m).

Agroforestry

An agroforestry system is a multifunctional system where cocoa is deliberately grown on the same plot as other trees and/or crops.

a) What is the more common form of cultivation in your area?

b) Do you think the cultivation method of **a)** is better or worse than the other method? Justify your answer.

3) Climate Change – Example: Long term temperature development

Introduction

Task 1:

Monthly mean temperature in Accra	
August 2017	27°C
August 2018	25°C

In Accra mean temperatures in August 2018 were 2°C lower than in August 2017. This is a sign that the climate in Accra is getting colder!

Sam

a) Do you think Sam is right about that conclusion? O yes O no

b) Justify your answer:

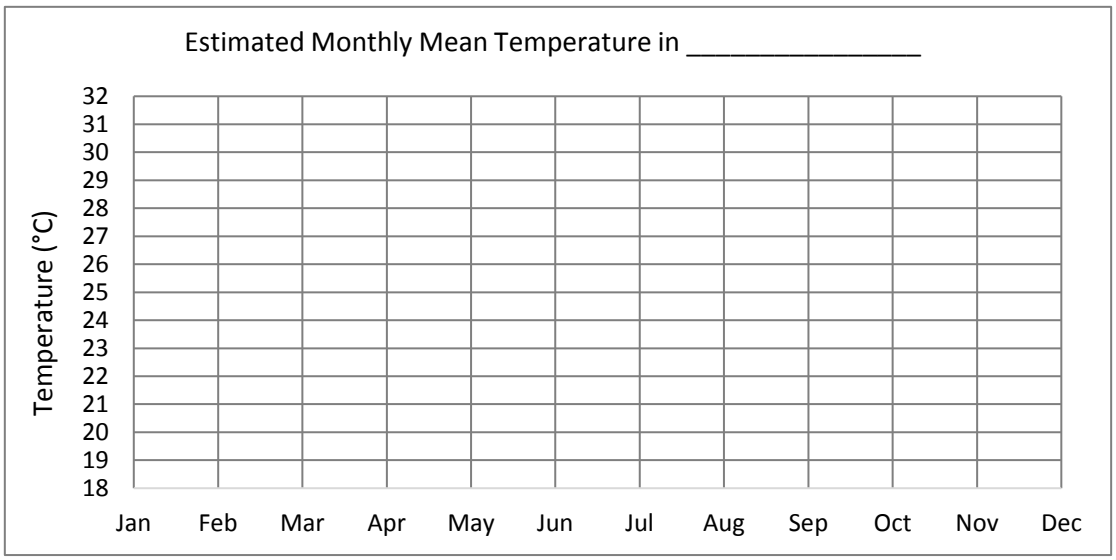
c) Discuss your answer with your seat neighbour and in class.

Monthly Temperatures

The monthly average temperature of a location is calculated from the daily mean values of the month in question. The daily mean value is computed by measuring the air temperature values at each hour and then calculating the mean value.

Task 2: Use a drawing to explain how the average monthly temperature of a location is calculated.

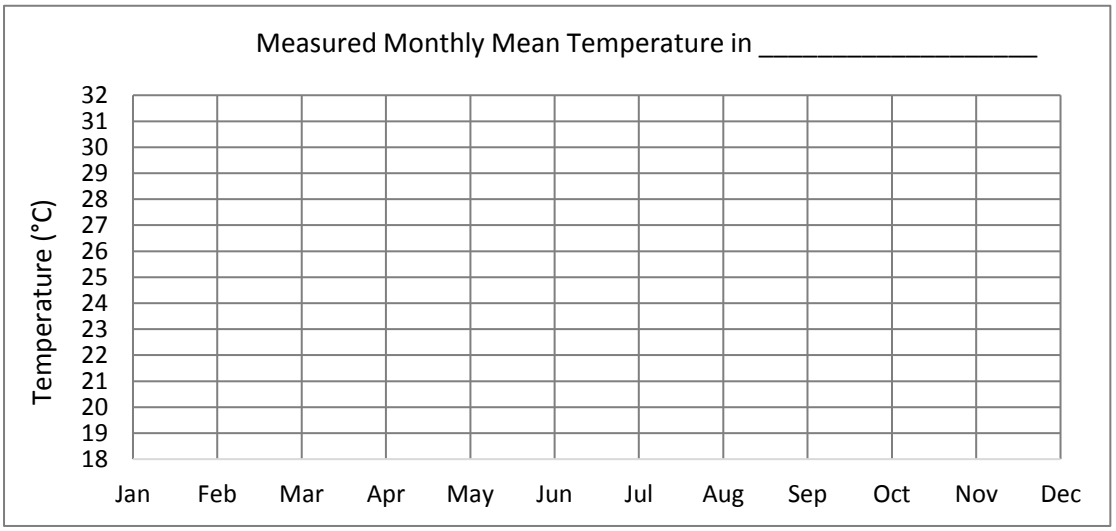
Task 3: Estimate the average temperatures for each month in your town. Enter the estimates in the graph below (draw points and connect them with a line).



Task 4: The following table shows the average monthly temperatures measured at your site in 2017. Enter the values in the graph.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Bibiani (GHA)	27	30	29	29	28	27	26	26	26	27	27	27
Mampong (GHA)	28	30	30	29	28	27	26	26	26	27	28	28

Table 1: Monthly mean temperatures (°C) at Bibiani / Mampong (measured 2017)



Task 5: Describe the temperature curve in Task 4 (e.g. when do maximums occur, when minimums?). Compare the curve with your estimate in Task 3.

Annual Temperatures in Ghana

Task 6:

a) Read the information text and summarize in one sentence what is meant by "weather" and "climate".

Information Text:
Weather is what we experience every day. It is the noticeable, short-term state of the atmosphere at a certain point on the earth's surface, which is manifested as sunshine, clouds, rain, wind, heat or cold. The term "climate" refers to the average weather over a longer period of time at a specific location. "Climate" is therefore not directly measurable anywhere, but a statistic from many measurements. The area can be small or large, a city or a continent or the whole globe. The period must be large enough for the formation of a statistical mean value. The reference period for determining the present climate is 30 years, usually 1961-1990. If the climate variables, i.e. temperature, precipitation, wind, evaporation, etc., fluctuate around a long-term mean value, the climate remains stable. If the mean value and the variability of the extremes change noticeably over time, there is climate change.

Weather:_____

Climate:_____

b) Decide whether the following statements concern the *weather* (W) or the *climate* (C).

__ There will be a strong wind coming from the west tomorrow.

__ Greenland has temperatures above 0° Celsius only in summer!

__ Due to the extremely strong El Niño last year there were floods along the western coast of South America.

__ In the tropical rainforest it rains regularly throughout the year.

c) Make up new statements and ask your classmates if these concern *weather* or *climate*.

_____

_____

_____

_____

_____

_____

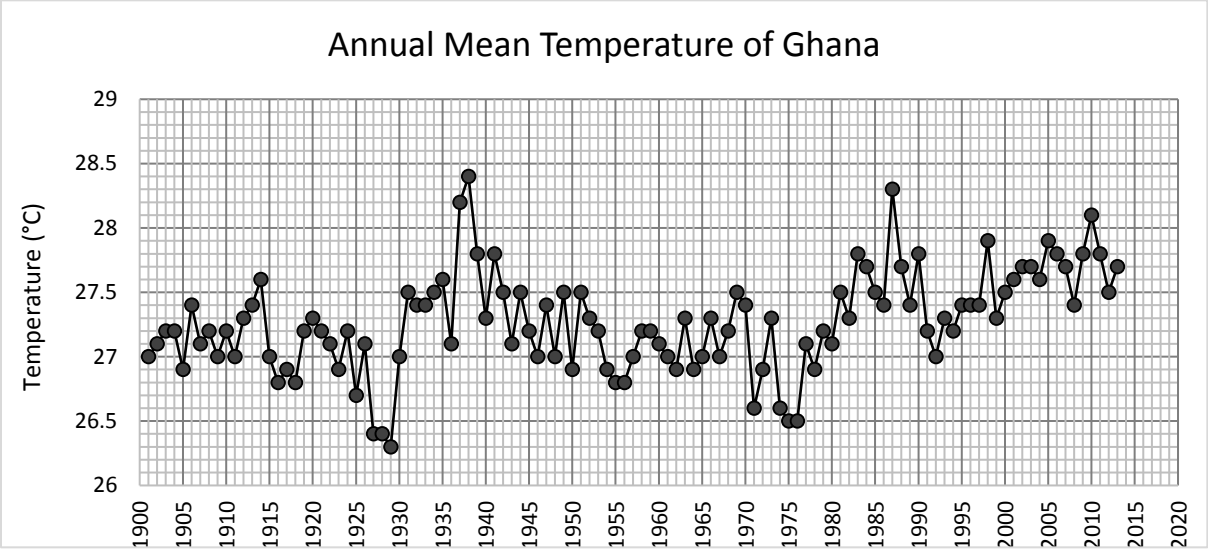
Task 7:

a) Calculate the average annual temperatures of Ghana for the years 2014-2017.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Mean T (°C)
2014	28.2	29.4	29.9	29.6	28.5	27.5	26.6	25.9	26.1	27.4	28	27.1	_____
2015	26.8	29.9	30.1	30.1	29.5	27.7	26.6	26	26.6	27.5	28.1	26.5	_____
2016	27.8	30	30.5	30.4	29.1	27.2	26.3	26.2	26.5	27.8	28.5	28.1	_____
2017	27.8	29.8	30.7	30.2	28.8	27.1	26.5	25.8	26.5	27.8	27.9	27.4	_____

Table 2: Monthly and yearly mean temperatures (°C) of Ghana

b) Insert the calculated values from **a)** in the following graph.



Task 8: The World Meteorological Organization (WMO) has established so-called *climate normal periods*. These include a fixed reference period of 30 years. Such intervals serve, among other things, for the comparability of the climatic variables among each other. The period from 1961-1990 was defined by the WMO as an internationally valid *reference period*.

a) Calculate the average temperature in Ghana for the *reference period* from 1961-1990 (use annual values from the graph for your calculation). _____

b) Draw the average temperature as a horizontal line in the graph. Color all dots above the average temperature red and the dots below blue.

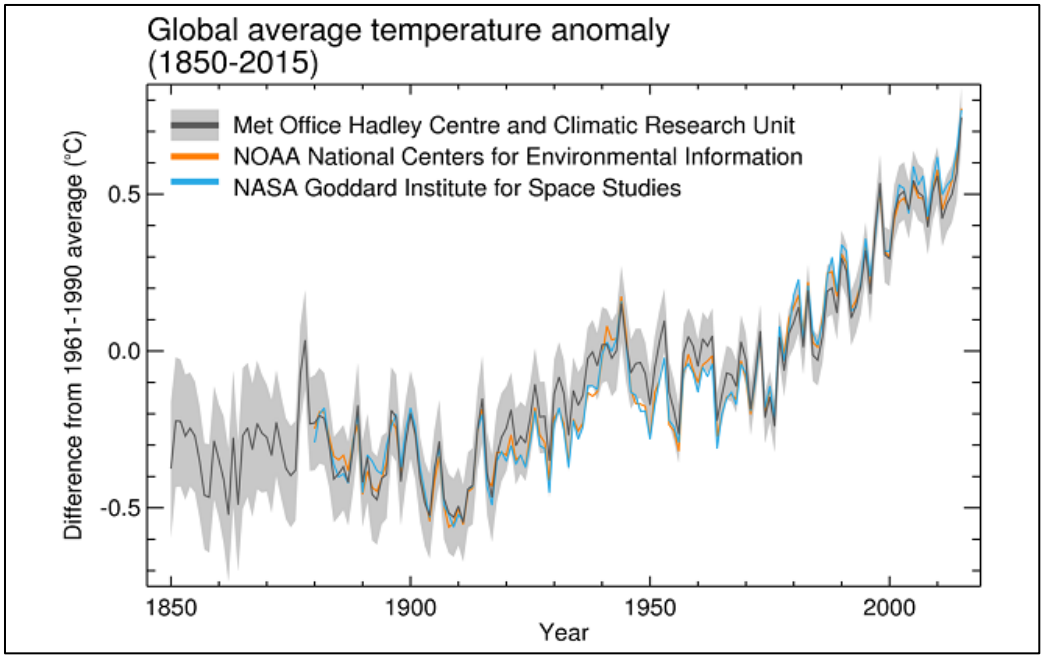
c) Analyse the graph:

1) Describe how the temperature in Ghana has changed since 1900 (e.g. maximum, minimum, tendency, frequency of years below/above average temperature, ...).

2) 1963, 1973 and 1998 were strong El Niño years, 1999 and 2008 strong La Niña years. Look at the temperatures of these years in the graph. What is your conclusion?

Global Annual Temperatures

Task 9:



Graph 1: Annual global average temperature anomalies (relative to 1961-1990) from 1850 to 2015 from different agencies. Credit: World Meteorological Organization

a) Read the title, the legend and the x- and y-axis of the graph above. What does the graph show? Explain.

b) Describe the temperature variations.

c) Compare the graphs "global average temperature" and "annual mean temperatre of Ghana." What similarities/differences do you see?

d) Why is the global temperature rising? Use the greenhouse effect for your explanation.

Task 10: Check out Sam's statement again. How should Alice respond to his statement?

In Accra mean temperatures in August 2018 were 2°C lower than in August 2017. This is a sign that the climate in Accra is getting colder!

Sam

Alice

Digression: Greenhouse effect

The majority of short-wave sunrays pass relatively unhindered through the atmosphere. When the sun's rays hit the Earth's surface, they heat it up. Short-wave solar radiation is thus converted into heat energy. We all know that dark objects heat up when they are in the sun. The heat energy is radiated back from the earth's surface as long-wave heat radiation. However, a small part of the sun's rays is not converted into thermal energy but reflected, for example when the sun's rays hit ice surfaces, snow or clouds.

What are greenhouse gases?

Greenhouse gases are gaseous components of the atmosphere that cause the so-called greenhouse effect. Examples of greenhouse gases are:
- Water vapour (H_2O)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Ozone (O_3)
- Laughing gas (N_2O)

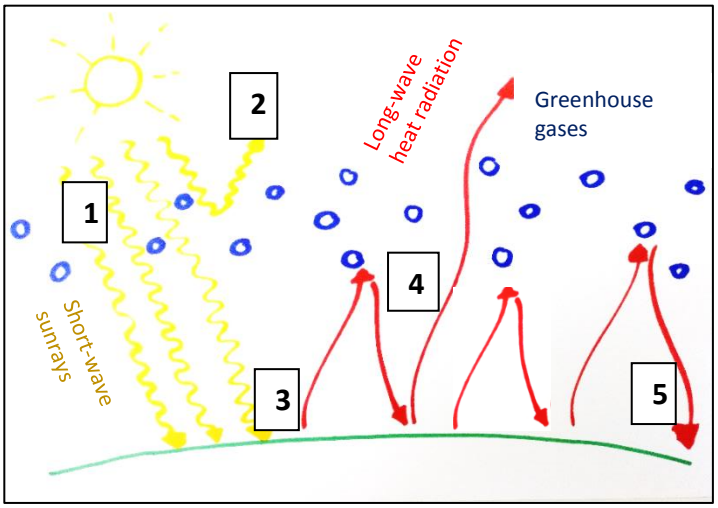
If all the long-wave heat radiation were to return to space, it would be bitterly cold on Earth: an average of -18°C! With such temperatures, no life would be possible on Earth. Today, however, the average temperature is about 15 °C. The reason for this are the so-called greenhouse gases in the atmosphere (→ see box). They retain part of the long-wave heat radiation, which additionally warms the atmosphere and the Earth's surface (see figure below). These greenhouse gases thus act like the glass roof in a greenhouse - hence the name. The influence of greenhouse gases on Earth's temperature is called the "greenhouse effect."

Task 1: The text describes the greenhouse effect. See the figure below and explain the greenhouse effect in your own words.

1) _____
_____
_____
_____

2) _____
_____
_____
_____

3) _____
_____
_____
_____



4) _____
_____

5) _____
_____

Task 2: Answer the questions.

a) What would the state of the Earth be without the natural greenhouse effect?

b) What happens to the average temperature on Earth when the proportion of greenhouse gases in the atmosphere increases? Explain your answer with a sketch.

□ The temperature remains unchanged

□ The temperature is rising

□ The temperature drops

Sketch:

4) Analysis of individual factors in cocoa cultivation

A1) Temperature: Measurement at School Site

Name of School: _____

Names of group members: _____

Date: Year: _____ Month: _____ Day: _____ Time: _____

Question:
How does the temperature fluctuate under different tree species or in different places in the school grounds?

Hypothesis:

_____
_____
_____
_____

Procedure:	**Material:**
1. Go to the school grounds and find a location for your measurement. 2. Describe your location using the table below. 3. Hold the thermometer at chest height and away from your body. 4. Wait until the temperature on the display does not change for 15 seconds. 5. Write down the measured temperature in the table. 6. Find a new location and repeat steps 1-5.	☐ Pen or pencil ☐ Thermometer (sensitivity 0.1°C)

Protocol:

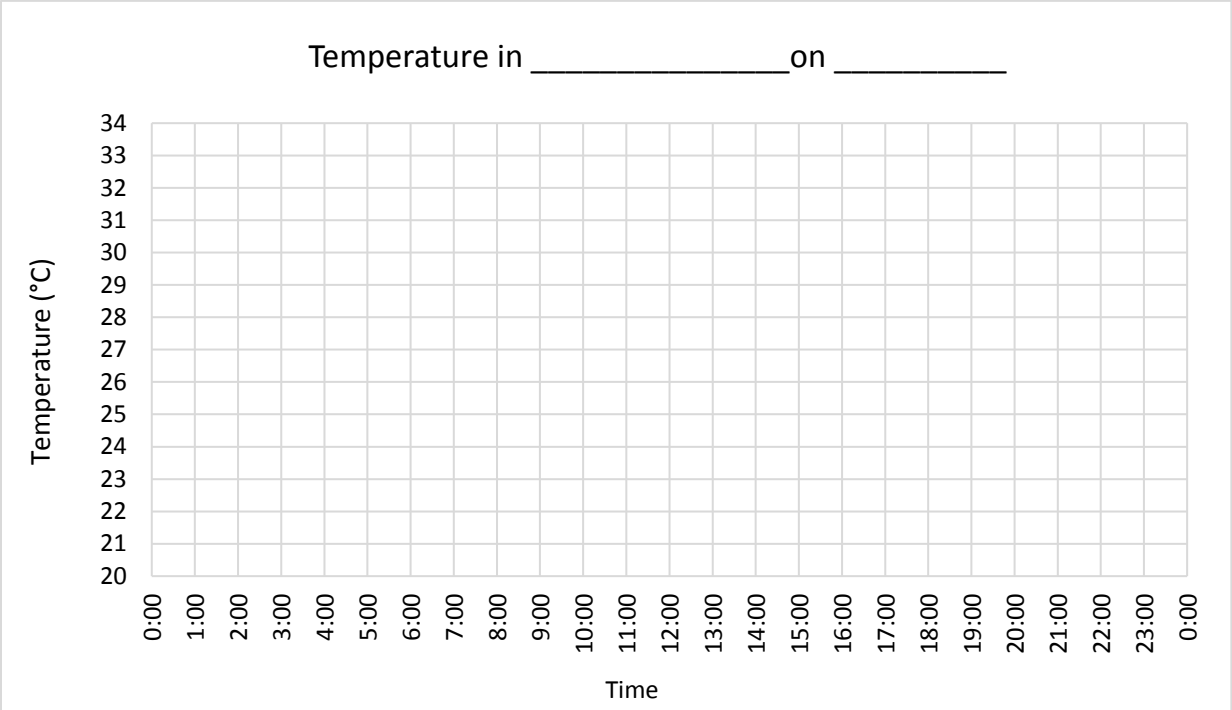
Location of the site (e.g. in a dense forest, underneath different single standing trees, in direct sunlight,…)	**Surface** (e.g. asphalt, grass…)	**Measurement in the <u>shade</u> or <u>sun</u>?**	**Measured temperature** (in °C)

Interpretation:

_____
_____
_____
_____
_____

A2) Temperature: Data Analysis

Task 1: The Trans-African HydroMeteorological Observatory (TAHMO) aims to develop a vast network of weather stations across Africa. Use the weather data of the TAHMO station in your area to draw yesterday's temperature curve in the graph.



Task 2: Describe the temperature curve in Task 1 (e.g. when was it warmest and coldest in the course of the day? Why? What was the temperature difference between maximum and minimum?).

_____

_____

_____

_____

_____

Information Text for Task 3:

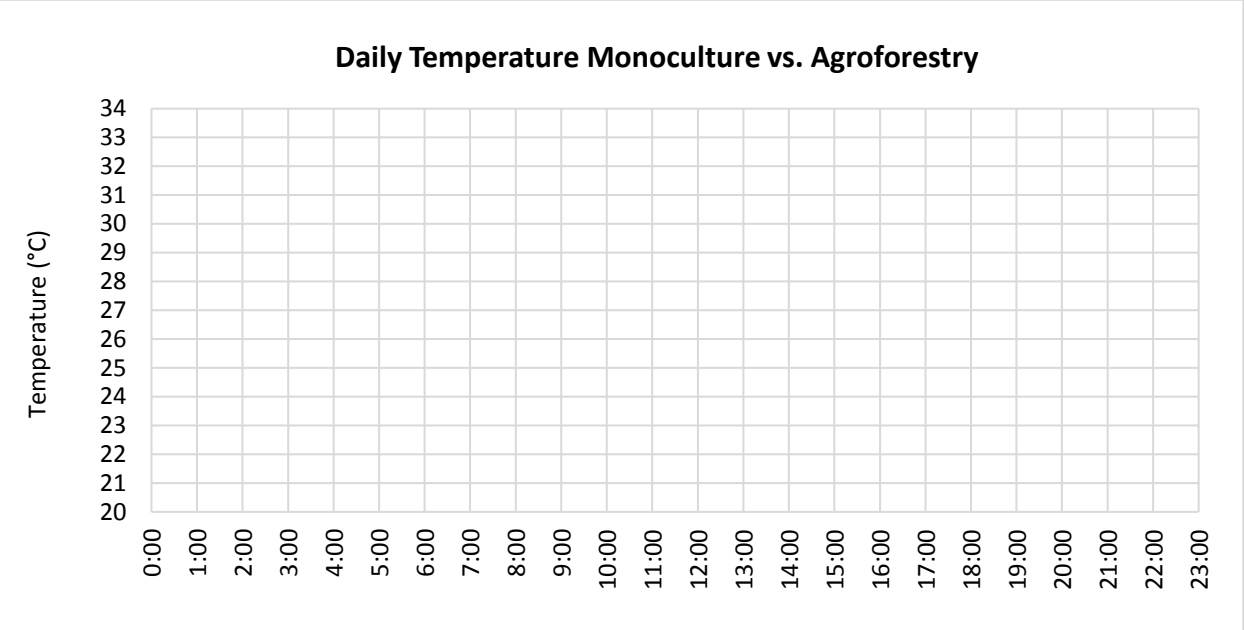
In Ghana, a scientific study[2] was conducted on the differences between cocoa monoculture and agroforestry systems. Various parameters such as production, soil fertility, diseases, climate variables etc. were measured at 20 locations for 3.5 years. One study site was in the village Anyinamso in the Atwima Nwabiagya district (see map). The investigated cocoa monoculture (without shade-trees) and the agroforestry system (with 177 shade-trees per hectare) were 50 meters apart.

[2] *Blaser et.al. (2018). Climate-smart sustainable agriculture in low-to-intermediate shade agroforests. Nature Sustainability, vol. 1, 234–239*

Task 3:

a) The table shows the measured temperature data (hourly average) in the cocoa monoculture and agroforestry system in Anyinamso (see Information text above). Transfer the measured values to the graph. Use different colours for the monoculture and the agroforestry system.

Time	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Agroforestry T (°C)	23	23	23	22	22	22	22	23	25	27	28	30	31	32	32	31	31	29	27	26	25	24	24	23
Monoculture T (°C)	23	23	22	22	22	22	22	23	25	28	30	31	32	33	33	33	32	30	27	25	24	24	23	23



b) Compare the temperature curve in the cocoa monoculture and in the agroforestry system. What are the similarities and differences?

c) Climate scenarios show that global temperatures will rise and that more and more extreme weather events will occur. Which cultivation system do you think is better due to the climate scenarios (considering the temperature)? Justify your answer.

B1) Light: Measurement at School Site

Name of School: _____

Names of group members: _____

Date: Year: _____ Month: _____ Day: _____ Time: _____

Question:

How much light is available for a cocoa plant below a shade-tree?

Procedure:	**Material:**
Note: This experiment can only be performed when the sun is shining. 1. Go to the schoolyard and find a tree. Note the tree species in the log below. 2. Throw a little stone at the shadow of the tree (not too close to the trunk, and not at the edge of the shadow area). Put the A3 paper on the ground where the stone landed. 3. Look at the shadow on the paper. What percentage of the paper is covered with shadow? Use Figure 1 to estimate the percentage of shadow area. 4. Record the estimated shadow area. 5. Repeat the procedure in 2 more places below the shadow tree. 6. Select two more trees in the schoolyard and repeat step 1-5.	☐ Little stone ☐ A3 Paper

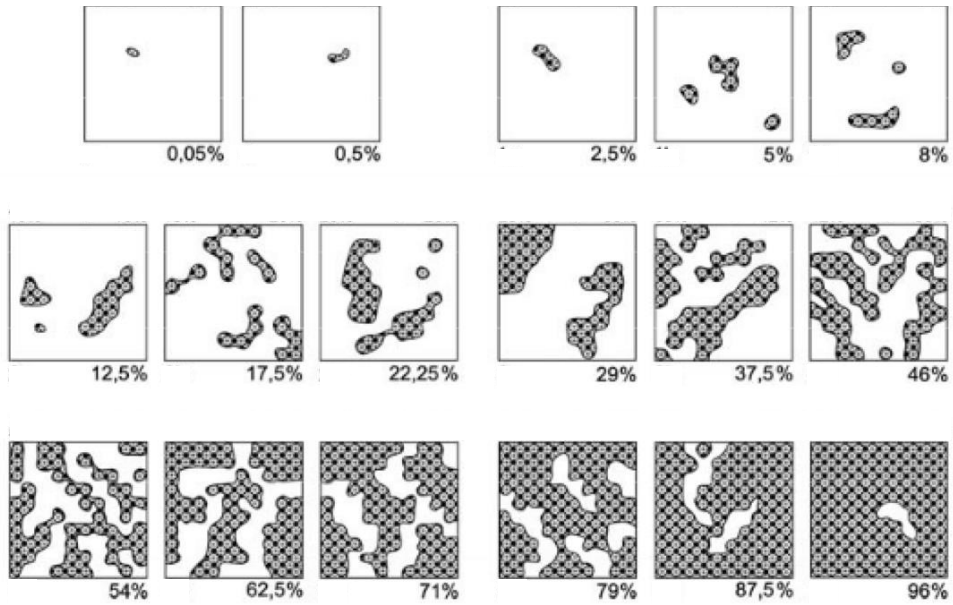


Fig. 1: *Scheme appreciation of abundance dominance after Braun-Blanquet method.*

Observed measurements:

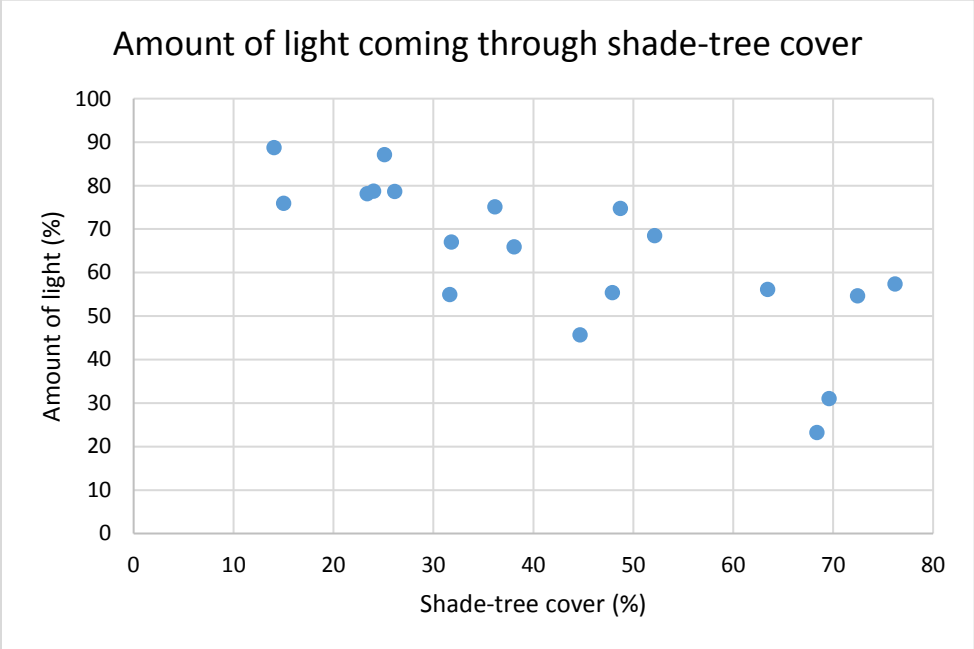
Tree species	**Estimated shaded area 1**	**Estimated shaded area 2**	**Estimated shaded area 3**

Analysis of observed measurements:

B2) Light: Data Analysis

Task: A scientific study[3] in Ghana investigated how much light passes through the shade-tree cover. For their study, the researchers analysed 20 plots (each with an area of 30mx30m). First, they took aerial photographs of the plots with drones and used the photos to calculate what percentage of the area was covered by shade-trees (=”shade-tree cover”). Using a sensor, they measured how much radiation is present above and below the shade-trees. They then calculated how much of the light (in %) passes through the canopies of the shade-trees. On the basis of 36 individual measurements, they calculated an average value per plot.

a) Look at the figure below. What does it show? Explain what the x-axis, y-axis and the points represent.



b) Draw a straight line through the points so that the points are as close as possible to that line.

c) Analyse the graph: What relationship between shade-tree cover and amount of light can you recognize?

d) Interpret: What effects could your findings from c) have on the yield of cocoa trees in monoculture or agroforestry? Explain.

[3] *Blaser et al. (2018). Climate-smart sustainable agriculture in low-to-intermediate shade agroforests. Nature Sustainability, vol. 1, 234–239*

C1) Soil Moisture: Measurement at School Site — Guide

Question:
How does soil moisture change with the distance to shade-trees?

Hypothesis:

Procedure for Measuring Gravimetric Soil Moisture[4]:

Lab:

1. Calibrate the balance according to the manufacturer's directions.
2. Label your empty sample containers, measure the weights and record them in the table on the data sheet.

Field:

1. Select a tree and record the name of the tree species on the data sheet.
2. Stretch out the measuring tape along the transect you will measure (starting point should be at the trunk).
3. Locate the sampling points along the transect at 1m, 5m and 10m distance from the trunk.
4. Cut or pull away any grass or groundcover above your sample point.
5. With the trowel: Dig a hole 10-15cm in diameter down to 5cm. Leave this soil loose in the hole.
6. Remove from the loose soil any rocks larger than a pea (about 5mm), large roots, worms, grubs, and other animals.
7. Use your trowel to fill a soil container with approximately 100 g of the loose soil.
8. Immediately seal the container to hold in the moisture.
9. Record the *container number*, *mass of soil*, and *distance* to the shade-tree in the table on the data sheet.
10. Continue to collect a sample at each sampling point along the transect. Remember to remove rocks, large roots, and animals. Seal each container and record the *container number*, *mass of soil* and *distance* from the starting point of the transect in the table on the data sheet.

Lab:

1. Measure the mass of the sample containers with the wet soil.
2. Record the mass next to the appropriate container number in the table on the data sheet.
3. Open the sample containers and dry them (e.g. beneath a heating lamp or fireplace, in a drying oven (temperature not exceeding 105°C) or at sun).
4. Determine when the sample is dry by weighing the bag or can and sample, replacing in the sun (or next to a fireplace) for a few more hours and then weighing the sample again. When the mass of the sample does not change it can be considered dry. (Note: drying times vary based on drying method and soil water content; heating lamps may take 2-3 days to dry soil in a zip lock bag. Drying ovens should dry soil in a can overnight.)
5. Determine the mass of the dry soil sample and record it next to the appropriate container number in the table on the data sheet.
6. Repeat steps 1–5 for each soil sample.
7. Calculate the soil water content (see calculation in the last column of the table on the data sheet).

Note: Dried soil should be returned to the site to fill in holes.

Material:

- ☐ Pen or pencil
- ☐ 3 Soil sample containers (sealable bags or cans)
- ☐ Measuring tape
- ☐ Trowel
- ☐ Balance with 0.1 g sensitivity
- ☐ Soil drying oven or heating lamp or fire

[4] Slightly modified from the GLOBE Protocol "Gravimetric Soil Moisture"

C1) Soil Moisture: Measurement at School Site — Data Sheet

Name of School: _____

Names of group members: _____

Date samples collected: Year: _____ Month: _____ Day: _____

Time: _____

Shade-tree species: _____

Comments on the location:

_____
_____
_____
_____

Drying method: _____ Drying time: Hours/minutes _____

		A	**B**	**C**	**(B-C) / (C-A)**
Distance to shade-tree (m)	Container ID #	Mass of empty container (g)	Mass of wet soil and container (wet mass) (g)	Mass of dry soil and container (dry mass) (g)	Gravimetric soil water content (from calculations) (g/g)

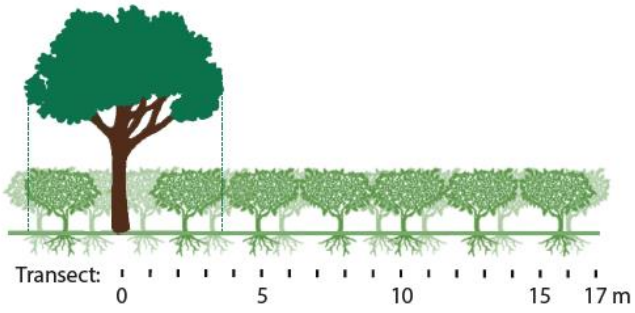
Interpretation of the measurements:

_____
_____
_____
_____
_____
_____
_____
_____
_____

C2) Soil Moisture: Data Analysis

Task:

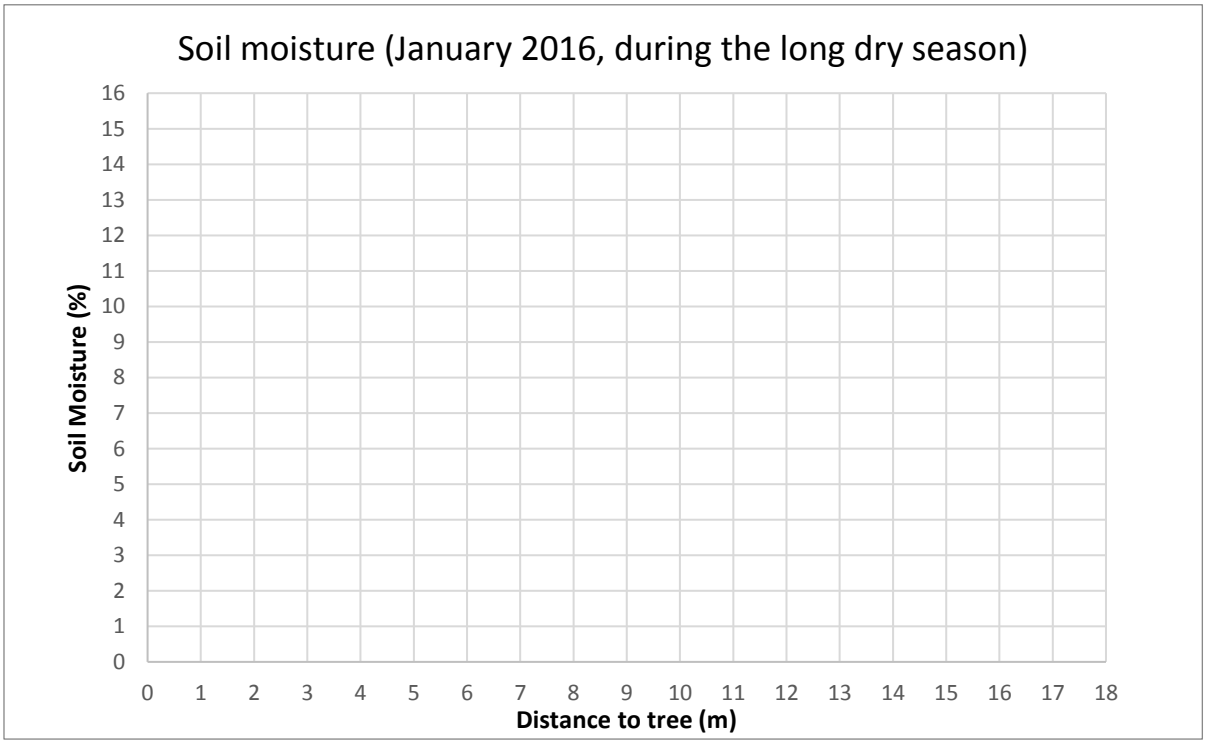
In January 2016, during the long dry season , a scientific study measured the soil moisture[5] along transects of different shade-trees in Ghana.



a) The following table shows the measured values[6]. Transfer the values to the graph below. Use a different colour for each tree species.

Tree Species	Distance to tree (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A	Soil moisture (%)	15.1	14.0	14.0	12.7	14.6	13.7	11.4	12.3	10.3	11.6	10.5	10.5	12.2	11.0	9.0	11.0	9.0
B	Soil moisture (%)	5.6	5.4	5.2	5.6	5.9	8.6	7.2	8.6	9.3	9.1	9.4	8.8	9.8	8.1	6.9	8.7	7.5

A = *Ficus capensis* (Odoma) / B = *Citrus senensis* (Orange)



b) Compare the soil moisture curves of Tree Species A (Odoma) and Tree Species B (Orange). How does each tree species influence soil moisture?

[5] The study measured the volumetric water content in % (= water volume / total volume *100)

[6] Blaser et al., unpublished. This data may only be used for teaching purposes.

c) What could be the reasons why the curves of the two tree species look like this?
(→ *Hint: In your answer, consider the roots of the trees and the canopy edge (Orange = 3m, Odomoa = 6m)*)

d) Considering the soil moisture: Are shade-trees on a cocoa plantation good or bad for the cocoa plants? Justify your answer.

D1) Biomass and Carbon Storage: Measurement at School Site

Name of School: _____

Names of group members: _____

Date: Year: _____ Month: _____ Day: _____

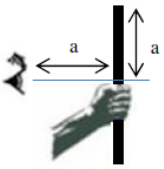
Procedure:

1. Go to the school grounds and pick a tree. Note the tree species in the table below.
2. Measure the height of the tree and the circumference at breast height using the instructions below.
3. Use the wood density list to find out the density of your tree species.
4. Calculate the stem diameter at breast height, the above ground biomass and the carbon storage using the equations 1, 2 and 3.
5. Repeat steps 1-4 for two more tree species.

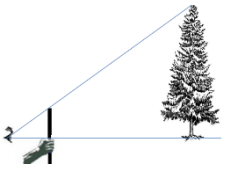
Material:

- ☐ Pen
- ☐ Measuring tape
- ☐ String
- ☐ Calculator

How to measure the height of a tree:



1. *With your arm outstretched, hold a stick so that the distances **a** (see figure) are the same. To make sure that the distances are the same: Tilt the stick with your outstretched arm until it reaches your shoulder.*
2. *Now move away from the tree and look over your outstretched arm until the uppermost part of the tree has just disappeared behind the upper stick end, and the lowermost part of the tree has disappeared behind the lower end of the stem.*
3. *Now measure the distance from your position to the tree. The height of the tree is identical to that measured distance.*



How to measure the circumference at breast height:

1. *Wrap your string around the tree trunk at 1.30m above ground level. Make sure that the string is straight and tight around the trunk, and mark or cut the circumference on the string.*
2. *Measure the length of string to get the circumference of the tree.*

Tree Species	Circumference at breast height **C** (cm)	Tree height **H** (m)	Wood density **ρ** (g/cm^3) → see database	Stem diameter at breast height **D** (cm) → see eq. 1	Above ground biomass **AGB** (kg) → see eq. 2	Carbon Stock **CS** (kg) → see eq. 3

Equation 1: D= C/π

Equation 2: $AGB_{\text{tree}} = 0.0673 \times (\rho D^2 H^2)^{0.976}$

Equation 3: CS = AGB x 0.49

D2) Biomass and Carbon Storage: Data Analysis

Task: A scientific study investigated the biomass in a cocoa monoculture and in an agroforestry system (cocoa agriculture). Below you will find some of the scientists' notes.

System: Cocoa Monoculture

Date: 20.6.2017

Place: Anyinamso, Ghana

Area: 900m²

Number of cocoa trees: 140

Total above ground biomass (AGB): 2025 kg

Note: Carbon stock = 0.49 x AGB

System: Cocoa Agroforestry

Date: 20.6.2017

Place: Anyinamso, Ghana

Area: 900m²

Number of cocoa trees: 134

Total above ground biomass (AGB) of cocoa trees: 1846 kg

Number of shade-trees: 16

Total AGB of shade-trees: 6427 kg

a) Calculate the average *above ground biomass* of a single cocoa tree in each system.

b) Calculate the average *above ground biomass* of a shade-tree in the cocoa agroforestry system.

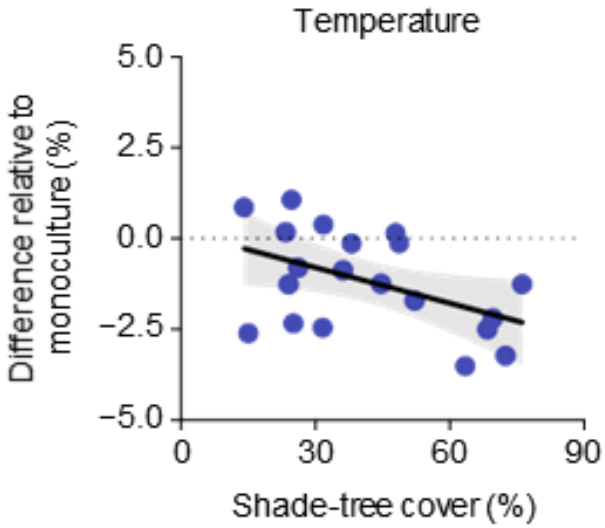
c) Calculate how much carbon is stored in the cocoa monoculture and in the cocoa agroforestry system.

d) A natural forest near the investigated area has a carbon stock of 211 tons C per hectare (1 hectare = 10'000m²). Compare the amount of carbon in the natural forest and in the cocoa monoculture and the agroforestry system (*Hint: Consider the units!).* What are your conclusions?

5) Synthesis and weighting of various factors

A) Introduction: How to read a graph

The following graph shows the air temperature in cacao agroforestry plots.



Think about the following questions and discuss them with your desk neighbour:

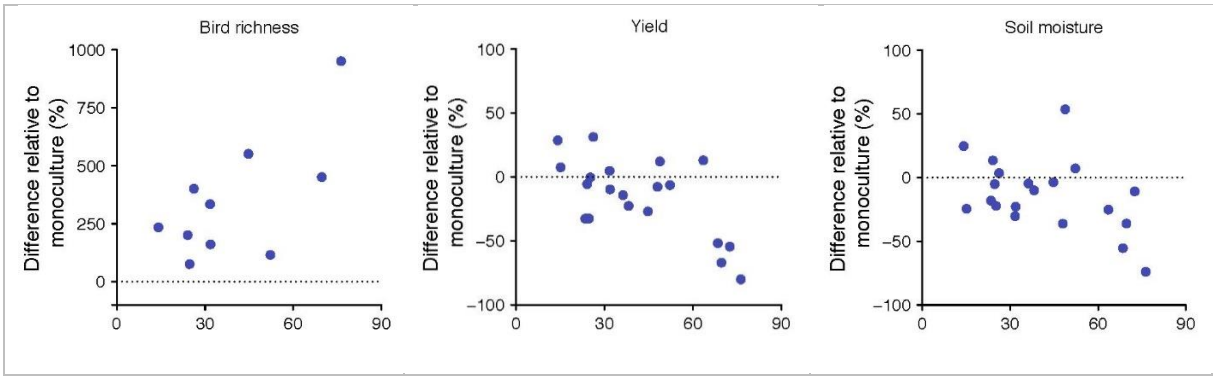
a) What does the x-axis show?
b) What does the y-axis show? What hints does the labelling of the y-axis give? What does the dotted horizontal line in the graph represent?
c) Why are there so many blue dots in the graph? What could they refer to?
d) What is the meaning of the black solid line?
e) What is the meaning of the grey shaded area that accompanies the black line?

B) Interpretation of the graphs

Task 1: After you know how to read the temperature graph above, explain its meaning in your own words to a classmate.

Task 2: The following graphs are of the same type as the temperature graph, only with other variables. In addition, the black solid line and the grey shaded area are missing in these graphs.

a) Draw a solid line in each of the three graphs, similar to the temperature graph above, which is characterised by the fact that all points have the smallest possible distance to the line.
b) Interpret each of the three graphs by explaining them in your own words to a classmate.



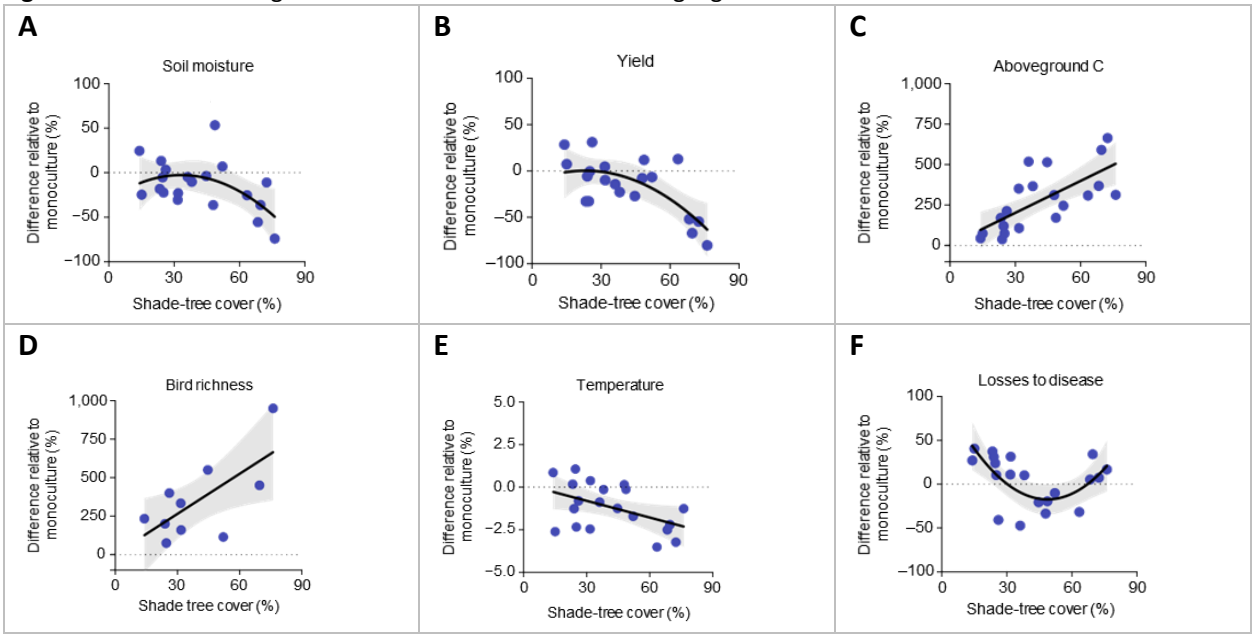
C) Synthesis and weighting

Task 1: Which of the following statements (Fig. 1) match which chart below (Fig. 2)?
Note: Not all statements match a graphic. Some graphs fit several statements.

Figure 1: Factors influencing the cultivation of cocoa, based on scientific research

1 Cocoa is most vulnerable to high temperatures and drought stress.	**2** Relative to monocultures, agroforests can have large benefits for biodiversity that do not strongly compromise yields up to a shade-tree cover of ~30%.	**3** The decrease in yield as shade-tree cover increases is likely to occur as a consequence of competition for light, water and nutrients.	**4** Agroforests (with high shade-tree cover) support higher levels of species diversity than monocultures.	**5** Conversion from high-shade to low-shade agroforests will come at the cost of a substantial loss of carbon storage capacity.
6 Increasing shade-tree cover has strong positive effects on aboveground carbon sequestration[7].	**7** High shade-tree cover decreases soil moisture. Many shade-trees apparently compete with cocoa trees in terms of soil moisture.	**8** Carbon sequestration[1] is particularly important for climate mitigation in regions where limited primary forest remains.	**9** Increasing shade-tree cover buffers cocoa against temperature extremes.	**10** There is clear evidence that rising temperatures may be an equally or more important threat to cocoa in West Africa than water availability.
11 The potential for climate mitigation through aboveground carbon storage in agroforests is a major advantage of agroforests over monocultures.	**12** Intermediate levels of shade (30-50%) may improve long-term production by minimizing losses to disease, even if these benefits do not exceed the monocultures.	**13** Shade-trees do not increase soil carbon stocks or other soil fertility parameters, including total soil nitrogen and phosphorus.	**14** The adaptability of agroforests to climate change depends on how the climate-related threats to production in a given area develop in concrete terms.	

Figure 2: The effects of agroforests on different variables along a gradient of shade-tree cover



Background information: The study was done in the Ashanti Region in Ghana. 20 agroforest plots were selected along a gradient of shade-tree cover ranging from low to high shade (14-76%). Each plot was paired with a nearby monoculture plot on the same farm.

Reference: Blaser WJ, Oppong J, Hart SP, Landolt J, Yeboah E, Six J. (2018). Climate-smart sustainable agriculture in low-to-intermediate shade agroforests. Nature Sustainability, vol. 1, 234–239. https://www.ethz.ch/en/news-and-events/eth-news/news/2018/05/optimum-shade-for-cocoa.html

[7] Carbon sequestration = carbon stored in aboveground standing biomass

Task 2: Remember the leading question of this teaching unit: “What is the best form of cocoa farming that both generates high yields and is climate-friendly and sustainable?” Against the background of this leading question, the statements in Fig. 1 can be assigned to specific categories. These categories are:
- Agricultural production
- Climate change, adaptation and mitigation
- Biodiversity conservation

Assign the statements in Fig. 1 to these three categories.

Task 3: Show the effect of shade-trees on different variables by translating the data of the corresponding graph (Fig. 2) with a colored pencil in the given bars below. The examples given for *bird richness* and *losses to disease* show you how to do so. **Note:**
- If the effect becomes more positive with increasing shade-tree cover, use blue color.
- Conversely, if the effect becomes more negative with increasing shade-tree cover, use red color.

	Shade-tree cover 10% 30% 50% 70%
Bird richness (Biodiversity conservation)	
Losses to disease (Agricultural production)	
Yield (Agricultural production)	
Temperature (Climate change, adaptation and mitigation)	
Soil moisture (Climate change, adaptation and mitigation)	
Aboveground C (Climate change, adaptation and mitigation)	

Task 4:

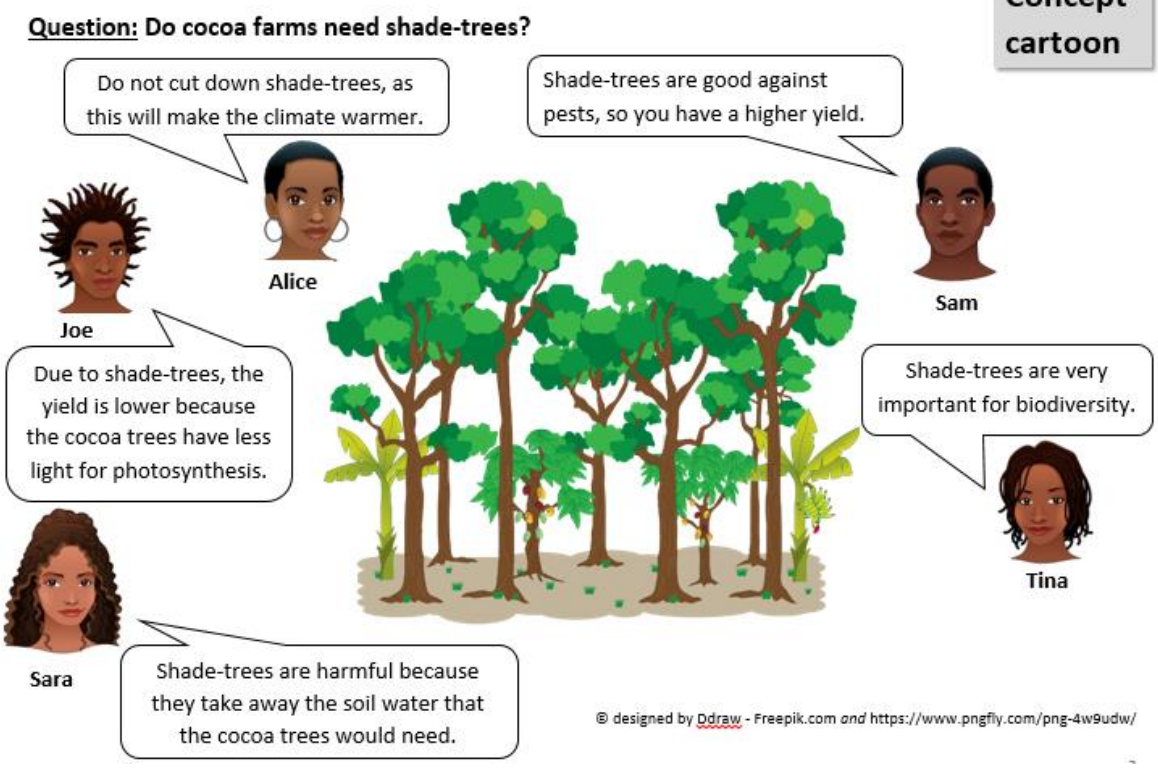
a) Now, by taking the results of Task 3, answer the following question: How much shade-tree cover is best to achieve good yields as well as being climate-friendly and good for biodiversity?

b) Then summarize for each variable why the range of the shade-tree cover you specify is the best.

Variable	*Reasons for the optimal shade-tree cover*
Bird richness	
Losses to disease	
Yield	
Temperature	
Soil moisture	
Aboveground C	

6) Final Task

Concept cartoon



Notes: