

A farmer has a pair of oxen, each weighing about 600kg that he uses for ploughing. The ox sustainable pull is about 12.5% of its weight. The oxen work for 6 hours per day and they are fed on hay. The plough cuts a furrow slice 20 cm wide by 25 cm deep. The specific soil resistance is 25kN/m<sup>2</sup> and oxen working speed is 3.6 km/h. Given the following additional information:

**Table 1 Energy content of typical animal feeds**

Feed	Dry Matter (%)	Gross Energy of Dry Matter (MJ/kg)	(DE/GE)
Guinea grass	26	7.4	0.50
Sudan grass	31	17	0.65
Hay (average quality)	85	17.4	0.55
Maize silage	27	18.8	0.75
Maize grain	86	19	0.80
Groundnut cake	90	20.7	0.85

Maintenance Energy = 8.3 + (0.091W) MJ/day, Where W is the mass of the draft animal

Appetite Limit = 0.025W kg of dry matter

Metabolisable Energy (ME) = 0.8 of Digestible Energy (DE)

Energy Conversion Efficiency of Draft Animals = 20%

a) Calculate the force required to pull the plough.

$$F = \frac{25\text{kN}}{\text{m}^2} \times \left( 20 \text{ cm} \times \frac{1\text{m}}{100\text{cm}} \times 25 \text{ cm} \times \frac{1\text{m}}{100\text{cm}} \right)$$

$$F = 1.25 \text{ kN}$$

b) Calculate the sustainable pull of the pair of oxen.

$$\text{ox sustainable pull} = \frac{12.5}{100} \times 600 \times 9.81 = 735.75 \text{ N}$$

for the pair of oxen:

$$\text{Sustainable pull} = 735.75\text{N} \times 2 = 1471.5\text{ N} = 1.472\text{kN}$$

c) State the condition under which the oxen will pull the plough.

sustainable pull must be greater or equal to the force required to pull the plough

d) Will the oxen pull the plough?

Yes

e) Calculate the power required to pull the plough.

$$P = F \times s$$

$$P = 1.25\text{kN} \times \frac{3.6\text{km}}{\text{h}} \times \frac{1000\text{m}}{\text{km}} \times \frac{1\text{h}}{3600\text{s}} \times \frac{1000\text{N}}{\text{kN}} = \frac{1250\text{Nm}}{\text{s}}$$

$$P = 1250\text{W} = 1.25\text{kW}$$

f) Calculate the daily maintenance energy requirement of the oxen ( $ME_{MR}$ ).

$$ME_{MR} = 2 \times (8.3 + 0.091 \times 600) = 125.8\text{ MJ/day}$$

g) Calculate the energy required to plough the field (in kWh and in MJ)  $E_{WD}$

$$E_{WD} = 1.25\text{kW} \times 6\text{h/day} = 7.5\text{kWh/day}$$

$$E_{WD} = \frac{7.5\text{kJh}}{\text{s day}} \times \frac{3600\text{s}}{\text{h}} = 27000\text{kJ/day}$$

$$E_{WD} = 27\text{MJ/day}$$

h) Calculate metabolisable energy required for ploughing ( $ME_{WD}$ )

Energy Conversion Efficiency of Draft Animals = 20%

$$ME_{WD} = \frac{E_{WD}}{0.20} = \frac{27\text{MJ}}{0.20} = 135\text{ MJ/day}$$

i) Calculate total metabolisable energy (to cover maintenance energy requirement and energy for ploughing) ( $ME_{TOT} = ME_{WD} + ME_{MR}$ )

$$ME_{TOT} = ME_{WD} + ME_{MR}$$

$$ME_{MR} = 125.8 \text{ MJ/day}$$

$$ME_{TOT} = 135 \text{ MJ/day} + 125.8 \text{ MJ/day} = 260.8 \text{ MJ/day}$$

- j) Calculate the Total Digestible Energy, DE of the pair of Oxen, required to meet total energy needs of the Oxen

Metabolisable Energy (ME)= 0.8 of Digestible Energy (DE)

$$DE = \frac{ME_{TOT}}{0.8} = \frac{260.8 \text{ MJ/day}}{0.8} = 326 \text{ MJ/day}$$

- k) Calculate the Total Gross Energy, GE of the pair of Oxen, required to meet total energy needs of the Oxen

$$\frac{DE}{GE} = 0.55$$

$$GE = \frac{DE}{0.55} = \frac{326 \text{ MJ/day}}{0.55} = 592.7 \text{ MJ/day}$$

- l) Calculate the quantity of hay requirement to cover total energy needs of the oxen (maintenance energy and energy for ploughing).

For hay, gross energy of dry matter = 17.4MJ/kg

$$\begin{aligned} \text{Dry matter needed} &= \frac{GE}{\text{gross energy of dry matter}} = \frac{592.7 \text{ MJ/day}}{17.4 \text{ MJ/kg}} \\ &= 34.1 \text{ kg/day} \end{aligned}$$

According to the Table, 85% of the mass of hay is dry matter.

$$\text{Therefore, } \frac{85}{100} \times \text{Mass of hay eaten/day} = 34.1 \text{ kg/day}$$

$$\text{Amount hay needed} = \frac{34.1}{0.85} = 40.1 \text{ kg/day}$$

- m) Calculate the Appetite Limit for the pair of oxen.

Appetite Limit = 0.025W kg of dry matter

$$\text{Appetite Limit} = 2 \times 0.025 \times 600 \text{ kg} = 30 \text{ kg}$$

n) State the condition under which the oxen will need supplementary feed.

If appetite limit is less than amount of dry matter needed, oxen will need supplementary feed because the amount of dry matter required to meet the total energy requirement of the oxen will be greater than the maximum amount of dry matter that the oxen can eat per day.

o) State two characteristics of a good supplementary feed.

The two important characteristics of a good supplementary feed are:

- i) high energy content
- ii) high digestibility (high DE/GE Ratio)

p) Will the oxen need supplementary feed?

Yes, because appetite limit of the oxen is 30 kg of dry matter per day while 34.1 kg of dry matter per day are required to meet the energy requirement of the oxen.

q) If so, calculate the quantity of groundnut cake supplement required.

Let

$h$  = amount of hay eaten by oxen, kg/day

$g$  = amount of groundnut cake eaten by oxen, kg/day

Create simultaneous equations

Equation 1 (total amount of dry matter should be 30 kg/day):

$$0.85h + 0.90g = 30 \text{ -----(1)}$$

Equation 2:

Find total gross energy of dry matter in the hay:

$$GE_{\text{hay}} = 17.4 \times (0.85h) = (14.79h) \text{ MJ/day}$$

Find the gross energy of the dry matter in the groundnut cake:

$$GE_{\text{cake}} = 20.7 \times (0.90g) = (18.63g) \text{ MJ/day}$$

Find the digestible energy of the hay:

$$\frac{DE_h}{GE_h} = 0.55$$

$$DE_h = 0.55 \times GE_h = 0.55 \times (14.79h) \text{MJ/day} = (8.1345h) \text{ MJ/day}$$

Find the digestible energy of the groundnut cake:

$$\frac{DE_g}{GE_g} = 0.85$$

$$DE_g = 0.85 \times (18.63g) \text{MJ/day} = (15.8355g) \text{MJ/day}$$

Find the total digestible energy from the two feeds:

$$DE_{TOT} = DE_h + DE_g = (8.1345h + 15.8355g) \text{ MJ/day}$$

Metabolisable Energy (ME) = 0.8 of Digestible Energy (DE)

$$ME_{TOT} = 0.8 \times DE_{TOT} = 0.8(8.1345h + 15.8355g) \text{ MJ/day}$$

$$ME_{TOT} = ME_{WD} + ME_{MR}$$

$$ME_{WD} = ME_{TOT} - ME_{MR}$$

$$ME_{MR} = 125.8 \text{ MJ/day [from part (f)]}$$

$$ME_{WD} = ME_{TOT} - ME_{MR} = [0.8(8.1345h + 15.8355g) - 125.8] \text{ MJ/day}$$

$$E_{WD} = 0.20 \times ME_{WD}$$

$$E_{WD} = \{0.20 \times [0.8(8.1345h + 15.8355g) - 125.8]\} \text{ MJ/day}$$

$$E_{WD} = 27 \text{ MJ/day [from part (g)]}$$

$$0.20 \times [0.8(8.1345h + 15.8355g) - 125.8] = 27$$

$$0.8(8.1345h + 15.8355g) - 125.8 = \frac{27}{0.20}$$

$$0.8(8.1345h + 15.8355g) = \frac{27}{0.20} + 125.8$$

$$8.1345h + 15.8355g = \frac{\frac{27}{0.20} + 125.8}{0.8} = 326$$

$$8.1345h + 15.8355g = 326 \text{-----(2)}$$

Solving simultaneous equations:

$$0.85h + 0.90g = 30 \text{ -----(1)}$$

$$8.1345h + 15.8355g = 326 \text{ -----(2)}$$

Equation 1:

Make “h” the subject of the formula:

$$0.85h + 0.90g = 30$$

$$h = \frac{30 - 0.90g}{0.85}$$

Equation 2:

Substitute the right-hand-side for “h” in equation 2.

$$8.1345h + 15.8355g = 326$$

$$8.1345 \left( \frac{30 - 0.90g}{0.85} \right) + 15.8355g = 326$$

$$287.1 - 8.613g + 15.8355g = 326$$

$$287.1 + 7.2225g = 326$$

$$g = \frac{326 - 287.1}{7.2225} = 5.39 \text{ kg/day}$$

Amount of groundnut cake = 5.39 kg/day

$$h = \frac{30 - 0.90g}{0.85} = \frac{30 - (0.90 \times 5.39)}{0.85} = 29.6 \text{ kg/day}$$

Amount of hay needed = 29.6 kg/day

- r) What would be the long term effect of not giving the oxen supplementary feed.

The oxen will lose weight. The appetite limit for the pair of oxen is 30 kg. This means that the oxen can only eat a maximum of 30 kg of dry matter per day. Since the quantity of hay needed to meet the total daily energy requirement for the pair of

oxen is 34.1kg and the oxen can only eat a maximum of 30 kg of dry matter per day, the oxen will have an energy deficit which would be met by catabolising fats and, under extreme situation, proteins. This would lead to loss of body weight, which will in turn result in reduced pull since the amount of pull an ox exerts is proportional to its weight.

- s) Calculate the amount of hay required to feed the oxen per year, given that the oxen work for 5 weeks of the year and no physical work during the rest of the year.

**During the 5 weeks of the year, amount of hay to feed oxen**

$$= 29.6 \frac{\text{kg}}{\text{day}} \times 5 \text{ weeks} \times \frac{7 \text{ days}}{\text{week}} = 1035.70 \text{ kg}$$

**During any other time, oxen only need maintenance rations.**

$$\text{ME}_{\text{MR}} = 125.8 \text{ MJ/day}$$

$$\text{ME}_{\text{WD}} = 0 \text{ MJ/day}$$

$$\text{ME}_{\text{TOT}} = \text{ME}_{\text{WD}} + \text{ME}_{\text{MR}} = 0 + 125.8 = 125.8 \text{ MJ/day}$$

Metabolisable Energy (ME) = 0.8 of Digestible Energy (DE)

$$\text{DE} = \frac{\text{ME}_{\text{TOT}}}{0.8} = \frac{125.8 \text{ MJ/day}}{0.8} = 157.25 \text{ MJ/day}$$

$$\frac{\text{DE}}{\text{GE}} = 0.55$$

$$\text{GE} = \frac{157.25 \text{ MJ/day}}{0.55} = 285.9 \text{ MJ/day}$$

$$\text{Amount of dry matter} = \frac{285.9 \text{ MJ/day}}{17.4 \text{ MJ/kg}} = 16.4 \text{ kg/day}$$

$$\text{Amount of hay needed} = \frac{16.4 \text{ kg/day}}{0.85} = 19.3 \text{ kg/day}$$

Assuming 365 days in a year, total number of days of no work done = 365 days –  $\left(\frac{7 \text{ days}}{\text{week}} \times 5 \text{ weeks}\right) = 330 \text{ days}$

$$\text{Amount of hay needed} = 19.3 \text{ kg/day} \times 330 \text{ days} = 6379.3 \text{ kg}$$

$$\text{Total hay needed per year} = 1035.70 \text{ kg} + 6379.3 \text{ kg} = 7.415 \text{ t}$$

- t) Calculate the area required to grow the hay, assuming an average gross yield of hay of 12.5 tonnes/ha at 85% dry matter content.

$$\text{Area needed} = \frac{\text{yield needed}}{\text{yield/ha}} = \frac{7.415 \text{ t}}{12.5\text{t/ha}} = 0.593 \text{ ha}$$