Case A: Sugar beet-cotton rotation in Guadalquivir Valley (reclaimed marshland in Lebrija)

Expected yields: 4 t/ha cotton fiber+seed ; Sugar beet 60 t/ha;

Cotton residues are chopped and incorporated by deep tillage. Sugar beet residues are removed from the field.

Soil analysis (0-30 cm): Texture clay

Bulk density 1.3 t/m^3

Olsen P: 10 mg/kg

Acetate extractable K: 897 mg K/kg soil

Table 13.1. Harvest index cotton 0.25-0.40, sugar beet 0.50-0.70

We take mid values: Cotton HI = 0.32, Sugar beet HI = 0.6

Appendix chapter 32: %dry matter cotton fiber+seed = 91

%DM sugar beet: 20

Expected yields (in kg/ha dry matter)

Cotton 4000 x 0.91 = 3640 kg/ha

Sugar beet 60000 x 0.20 = 12000 kg/ha

Production of residues

Cotton 3640 x (1-HI)/HI = 3640 x (1-0.32)/0.32 = 7735 kg/ha

Sugar beet 12000 x (1-0.60)/0.40 = 8000 kg/ha

Thresholds (Table 26.2 for P, Table 26.3 for K)

P threshold 8-10 mg/kg (clay soil) or 15-20 mg/kg (sugar beet)

K threshold 200-300 mg/kg (clay soil): we take 250 mg/kg

Strategy for P: We take the upper threshold for sugar beet, 20 mg/kg (due to high yield) so the soil is below and we need to add more P than that exported

P exported with cotton crop (no residues are exported, %P in harvest is 0.41):

3640 kg/ha x 0.0041 kg P/kg = 14.9 kg P/ha

P exported with sugar beet crop (residues are exported, %P in harvest is 0.25, %P in residues is 0.22):

12000 kg/ha x 0.0025 kg P/kg + 8000 kg/ha x 0.0022 kg P/kg = 47.6 kg P/ha

Mean P export of rotation: 31.3 kg P/ha

P rate per year (calculated for 2 year buildup period)

$$P\ rate\ \left(kg\,\frac{P}{ha}\right) = Exported\ P + \frac{10\ \rho_b\ Z}{N_{year}}\ (STL_t - STL)$$
$$= 31.3 + \frac{10\ x\ 1.3\ x\ 0.3}{2}\ (20 - 10)\ = 50.7\ kg\ P/ha$$

Which may supplied with 50.7/0.2 = 253.8 kg triple superphosphate/ha. This amount should be added before planting of both cotton and sugar beet.

Strategy for K: The STL (897 mg/kg) exceeds the maintenance limit (500 mg/kg) which is twice the threshold shown in Table 26.3. Therefore we need to add less K than that exported. The possible alternatives are:

a) apply a fixed percentage of exported nutrient

b) reduce the fraction K rate/K exported from 1 at the maintenance limit to zero when the STL is equal to 3 STL_t. Let’s follow this strategy in the example.

According to the rule, as the STL exceeds 3 STL_t , we do not apply K fertilizer.

However, according to the rule, as the STL exceeds 3 STL_t , we do not apply K fertilizer.

Nitrogen fertilization

General equation (25.7, chapter 25)

$$N_f = \frac{N_{end} + (1 + f_{NR})\left(N_{yield} + N_{res}\right) -\ k_{im}\ F_{res}\ N'_{res} -\ f_{NR}\ \left(N'_{yield} + N'_{res}\right) -\ N_{other}}{(1 - n)}$$

Assumptions

N_{end} 40 kg/ha (mid value in the range indicated in 25.2.3)

f_{NR} 0.2

k_{im} 0.7 (non legumes with tillage)

N_{other} 10 kg/ha (upper in range indicated in 25.2.3)

F_{res} 1 for cotton as all residues are incorporated and 0 for sugar beet as residues are taken out of the field

1-n 0.90 (we aim at a high efficiency)

Amount of N in yield and residues (take lowest concentrations from Table 24.1)

Cotton N_{yield} = 3640 kg/ha x 0.0232 kg N/kg = 84.4 kg N/ha

Cotton N_{res} = 7735 kg/ha x 0.009 kg N/kg = 69.6 kg N/ha

Sugar beet N_{yield} = 12000 kg/ha x 0.009 kg N/kg = 108 kg N/ha

Sugar beet N_{res} = 8000 kg/ha x 0.018 kg N/kg = 144 kg N/ha

Cotton N fertilizer

$$N_f = \frac{10 + (1 + 0.2)(84.4 + 69.6) - 0.2\,(108 + 144) - 10}{0.90} = 149.4\ kg\ N/ha$$

Which may be supplied with 149.4/0.46 = 324.8 kg urea/ha

Sugar beet fertilizer

$$N_f = \frac{10 + (1 + 0.2)(108 + 144) - 0.7 \cdot 69.6 - 0.2\,(84.4 + 96.6) - 10}{0.9}$$
$$= 247.6\ kg\ N/ha$$

Which may be supplied with 247.6/0.46 = 538.3 kg urea/ha

Case B: Soybean-barley rotation under irrigation

Expected yields: 3.5 t/ha soybean ; 6 t/ha barley

Growing cycles: Soybean 1/4-30/9

Barley 1/11-30/6

Crop residues are left on the soil

Soil analysis (0-30 cm): Texture sandy loam

Bulk density 1.4 t/m^3

Olsen P: 8 mg/kg

Acetate extractable K: 200 mg K/kg soil

Organic matter concentration: 1%

Table 13.1. Harvest index soybean 0.35-0.50, barley 0.40-0.50

We take mid values: Soybean HI = 0.425, barley HI = 0.45

Appendix chapter 32: %dry matter soybean = 87.5

%DM barley: 88.5 (6-row barley)

Expected yields (in kg/ha dry matter)

Soybean	3500 x 0.875 = 3062.5 kg/ha
Barley	6000 x 0.885 = 5310 kg/ha

Production of residues

Soybean	3062.5 x (1-HI)/HI = 3062.5 x (1-0.425)/0.425 = 4143 kg/ha
Barley	5310 x (1-0.45)/0.45 = 6490 kg/ha

Thresholds (Table 26.2 for P, Table 26.3 for K)

P threshold 10-12 mg/kg (loam soils): we take 12 mg/kg

K threshold 150-175 mg/kg (loamy soil): we take 175 mg/kg

Strategy for P: The threshold is 12 mg/kg (due to high yield) so the soil is below and we need to add more P than that exported

P exported with soybean crop (no residues are exported, %P in harvest is 0.66):

3062.5 kg/ha x 0.0066 kg P/kg = 20.2 kg P/ha

P exported with barley crop (no residues are exported, %P in harvest is 0.42):

5310 kg/ha x 0.0042 kg P/kg = 22.3 kg P/ha

Mean P export of rotation: 21.3 kg P/ha

P rate per year (calculated for 2 year buildup period)

$$P\ rate\ \left(kg\,\frac{P}{ha}\right) = Exported\ P + \frac{10\ \rho_b\ Z}{N_{year}}\ (STL_t - STL)$$
$$= 21.3 + \frac{10\ x\ 1.4\ x\ 0.3}{2}\ (12 - 8)\ = 29.7\ kg\ P/ha$$

Which may supplied with 29.7/0.2 = 148.3 kg triple superphosphate/ha. This amount should be added before planting of both soybean and barley.

Strategy for K: The STL (200 mg/kg) exceeds the threshold (175 mg/kg) but is below the maintenance limit (350 mg/kg) which is twice the threshold. Therefore we need to add only the amount of K that is exported.

K exported with soybean crop (no residues are exported, %K in harvest is 1.5):

3062.5 kg/ha x 0.015 kg K/kg = 45.9 kg K/ha

K exported with barley crop (no residues are exported, %K in harvest is 0.54)

5310 kg/ha x 0.0054 kg K/kg = 28.7 kg K/ha

Mean K export of rotation: 37.3 kg K/ha, which equals the required K as fertilizer

Which may be supplied with 37.3/ 0.415=89.9 kg potassium sulfate/ha. This is the mean amount of K fertilizer to apply before the two crops.

Nitrogen fertilization

Soybean is a legume so a large fraction of required N may come from N fixation. The amount fixed may be calculated using Eq. 24.1:

N_{fixed} =(1+f_{NR}) Y (NC_y+(1-HI)/HI NC_r) F_{NBF}

f_{NR} 0.2

Concentrations of N (Table 24.1)

NC_y 6.5% NC_r 0.85%

Table 24.2. Fraction of N coming from fixation. F_{NBF}=0.95

N_{fixed} =(1+0.2) 3062 (0.065+(1-0.425)/0.425 x 0.0085) 0.95 = 267 kg N/ha

Now we apply the general equation (25.7, chapter 25)

$$N_f = \frac{N_{end} + (1 + f_{NR})\left(N_{yield} + N_{res}\right) - k_{im}\, F_{res}\, N'_{res} - f_{NR}\left(N'_{yield} + N'_{res}\right) - N_{other}}{(1-n)}$$

For a soybean crop we assume that just some starter N fertilizer is applied (20 kg N/ha). Thefore from eq. 25.7 we may deduce N_{end} at harvest of the soybean crop. Taking k_{im}=0.7 we deduce N_{end}=62.7 kg/ha. For the next barley crop as we expect a low final N (10 kg/ha), we add a credit of 62.7-10=52.7 kg/ha to the N_{other} and then apply eq. 25.7 so N_f=35.8 kg N/ha

Assumptions

N_{end}	10 kg/ha for barley. Any remaining N after harvest of barley may be lost during autumn and winter
f_{NR}	0.2
k_{im}	0.7 (legumes not incorporated) for soybean residues
	0.5 (cereal not incorporated) for barley residues
N_{other}	10 kg/ha+267 kg/ha (for soybean)
	10 kg/ha +52.7 kg/ha (for barley)
F_{res}	1 for both crops
1-n	0.90 (we aim at a high efficiency)

Amount of N in yield and residues (take lowest concentrations from Table 24.1)

Soybean N_{yield} = 3062 kg/ha x 0.065 kg N/kg = 199 kg N/ha

Soybean N_{res} = 4143 kg/ha x 0.0085 kg N/kg = 35.2 kg N/ha

Barley N_{yield} = 5310 kg/ha x 0.016 kg N/kg = 85 kg N/ha

Barley N_{res} = 6490 kg/ha x 0.007 kg N/kg = 45.4 kg N/ha

In summary we have to apply before planting:

29.7 kg P/ha

37.3 kg K/ha

20 kg N/ha before soybean or 35.8 kg N/ha for barley (preplant or topdressing)

These quantities may be satisfied by different combinations of straight or complex fertilizers. For this rotation fertilizers including S are beneficial (for soybean). A possible combination is the following

For barley: 77.8 kg urea/ha (half preplant and half topdressing) + 89 kg potassium sulfate/ha (preplant)+148.5 kg triple superphosphate/ha (preplant)

For soybean: 76.9 kg ammonium nitrosulfate (preplant)+130 potassium phosphate (preplant)

Nutrient balance in the long term

To check the calculations it is always interesting to compute the mean inputs and outputs for N, P and K for the two-year rotation.

	N	P	K
Inputs	343	60	73.3
Outputs	284	43	74.6
Input-output	59	17	-1

The inputs include N fixation (267 kg/ha) and N in rain (20 kg N/ha in two years). The difference indicates that N losses and some accumulation as organic N is occurring. Potassium balance is nil (as expected) and phosphorus is accumulating (as expected from the P management strategy).

Case C: Wheat (15/10-15/07)-sunflower (1/4-15/8)-wheat (15/10-15/07)-lentil (15/4-31/8)

Expected yields: 5 t/ha wheat ; 2.5 t/ha sunflower; 2 t/ha lentil

Crop residues are incorporated by tillage

Soil analysis (0-30 cm): Texture sandy loam

Bulk density 1.4 t/m^3

Olsen P: 16 mg/kg

Acetate extractable K: 250 mg K/kg soil

Organic matter concentration: 1%

Table 13.1. Harvest index wheat 0.40-0.50, sunflower 0.25-0.40; lentil 0.35-0.50

We take mid values: Wheat HI = 0.45, sunflower HI=0.325; lentil HI = 0.425

Appendix chapter 32: %dry matter wheat = 87.5

%DM sunflower: 91.5

%DM lentil: 89

Expected yields (in kg/ha dry matter)

Wheat	5000 x 0.875 = 4375 kg/ha
Sunflower	2500 x 0.915 = 2287 kg/ha
Lentil	2000 x 0.89 = 1780 kg/ha

Production of residues

Wheat	4375 x (1-HI)/HI = 4375 x (1-0.45)/0.45 =5347 kg/ha
Sunflower	2287 x (1-0.325)/0.325 = 4751 kg/ha
Lentil	1780 x (1-0.425)/0.425 = 2408 kg/ha

Thresholds (Table 26.2 for P, Table 26.3 for K)

P threshold 10-12 mg/kg (loam soils): we take 12 mg/kg

K threshold 150-175 mg/kg (loamy soil): we take 175 mg/kg

Strategy for P: The threshold is 12 mg/kg (due to high yield) so the soil is above it but below the maintenance limit. Therefore we need to add only exported P

P exported with wheat crop (no residues are exported, %P in harvest is 0.37):

4375 kg/ha x 0.0037 kg P/kg = 16.2 kg P/ha

P exported with sunflower crop (no residues are exported, %P in harvest is 0.63):

2287 kg/ha x 0.0063 kg P/kg = 14.4 kg P/ha

P exported with lentil crop (no residues are exported, %P in harvest is 0.43):

1780 kg/ha x 0.0043 kg P/kg = 7.7 kg P/ha

Mean P export of 4-year rotation: 13.6 kg P/ha/year

P rate per year: 13.6 kg P/ha

Which may supplied with 13.6/0.2 = 68 kg triple superphosphate/ha. This amount should be added before planting of each crop.

Strategy for K: The STL (250 mg/kg) exceeds the threshold (175 mg/kg) but is below the maintenance limit (350 mg/kg) which is twice the threshold. Therefore we need to add only the amount of K that is exported.

K exported with wheat crop (no residues are exported, %K in harvest is 0.46):

4375 kg/ha x 0.0046 kg K/kg = 20.1 kg K/ha

K exported with sunflower crop (no residues are exported, %K in harvest is 0.72)

2287 kg/ha x 0.0072 kg K/kg = 16.5 kg K/ha

K exported with lentil crop (no residues are exported, %K in harvest is 0.86)

1780 kg/ha x 0.0086 kg K/kg = 15.3 kg K/ha

Mean K export of 4-year rotation: 18 kg K/ha/year, which equals the required K as fertilizer

Which may be supplied with 18/ 0.415=43.4 kg potassium sulfate/ha. This is the mean amount of K fertilizer to apply before each crop.

Nitrogen fertilization

Lentil is a legume so a large fraction of required N may come from N fixation. The amount fixed may be calculated using Eq. 24.1:

N_{fixed} =(1+f_{NR}) Y (NC_y+(1-HI)/HI NC_r) F_{NBF}

f_{NR} 0.2

Concentrations of N (Appendix chapter 24)

NC_y 4.3% NC_r 1.1%

Table 24.2. Fraction of N coming from fixation. F_{NBF}=0.95

N_{fixed} =(1+0.2) 1780 (0.043+(1-0.425)/0.425 x 0.011) 0.95 = 117 kg N/ha

Now we apply the general equation (25.7, chapter 25)

$$N_f = \frac{N_{end} + (1+f_{NR})\left(N_{yield} + N_{res}\right) - k_{im}\, F_{res}\, N'_{res} - f_{NR}\left(N'_{yield} + N'_{res}\right) - N_{other}}{(1-n)}$$

For a lentil crop we assume that no N fertilizer is applied. Thefore from eq. 25.7 we may deduce N_{end} at harvest of the lentil crop. Taking k_{im}=0.7 we deduce N_{end}=53 kg/ha. For the next wheat crop as we expect a low final N (10 kg/ha), we add a credit of 53-10=43 kg/ha to the N_{other} and then apply eq. 25.7 so N_f=71.7 kg N/ha

Then for sunflower, N_f=85.5 kg N/ha

And then for wheat, N_f=115.8 kg N/ha

Assumptions

N_{end} 10 kg/ha for all crops except for lentil

f_{NR} 0.2

k_{im} 0.9 (legumes incorporated) for lentil residues

0.7 (other crops, incorporated) for wheat and sunflower

N_{other} 10 kg/ha+117 kg/ha (for lentil)

10 kg/ha+43 kg/ha (for wheat after lentil)

10 kg/ha (for sunflower and wheat after sunflower)

F_{res} 1 for all crops

1-n 0.90 (we aim at a high efficiency)

In summary we have to apply:

13.6 kg P/ha (all crops)

18 kg K/ha (all crops)

71.7 kg N/ha for wheat after lentil

85.5 kg N/ha for sunflower

115.8 kg N/ha for wheat after sunflower

These quantities may be satisfied by different combinations of straight or complex fertilizers. For this rotation fertilizers including S are beneficial (for lentil). A possible combination is the following

Wheat after lentil: 156 kg urea/ha (50% preplant+50% topdressing)+ 68 kg triple superphosphate /ha (preplant)+43 kg potassium sulfate/ha (preplant)

Sunflower: 186 kg urea/ha (40% preplant+60% topdressing)+ 68 kg triple superphosphate /ha (preplant)+43 kg potassium sulfate/ha (preplant)

Wheat after sunflower: 252 kg urea/ha (30% preplant+70% topdressing)+ 68 kg triple superphosphate /ha (preplant)+43 kg potassium sulfate/ha (preplant)

Lentil: 68 kg triple superphosphate /ha (preplant)+43 kg potassium sulfate/ha (preplant)

Case D: Rapeseed-maize under irrigation

Expected yields: 4 t/ha rapeseed (1/10-30/6); maize 14 t/ha (1/4-31/8)

All crop residues are chopped and incorporated by deep tillage.

Soil analysis (0-30 cm): Texture sand

Bulk density 1.5 t/m^3

Olsen P: 4 mg/kg

Acetate extractable K: 80 mg K/kg soil

Table 13.1. Harvest index rapeseed 0.30-0.35, maize 0.40-0.55

We take mid values: Rapeseed HI = 0.325, Maize HI = 0.475

Appendix chapter 32: %dry matter rapeseed = 91

%DM maize: 86

Expected yields (in kg/ha dry matter)

Rapeseed	4000 x 0.91 = 3640 kg/ha
Maize	14000 x 0.86 = 12040 kg/ha

Production of residues

Rapeseed	3640 x (1-HI)/HI = 3640 x (1-0.325)/0.325 = 7560 kg/ha
Maize	12040 x (1-0.475)/0.475 = 13307 kg/ha

Thresholds (Table 26.2 for P, Table 26.3 for K)

P threshold 12-20 mg/kg (sandy soils): we take 20 mg/kg

K threshold 100 mg/kg (sandy soil

Strategy for P: the STL is below the threshold and we need to add more P than that exported

P exported with rapeseed crop (no residues are exported, %P in harvest is 0.62):

3640 kg/ha x 0.0062 kg P/kg = 22.6 kg P/ha

P exported with maize crop (no residues are exported, %P in harvest is 0.32)

12040 kg/ha x 0.0032 kg P/kg = 38.5 kg P/ha

Mean P export of rotation: 30.5 kg P/ha

P rate per year (calculated for 2 year buildup period)

$$P\ rate\ \left(kg\frac{P}{ha}\right) = Exported\ P + \frac{10\ \rho_b\ Z}{N_{year}}\ (STL_t - STL)$$
$$= 30.5 + \frac{10\ x\ 1.5\ x\ 0.3}{2}\ (20-4)\ = 66.5\ kg\ P/ha$$

Which may supplied with 66.5/0.2 = 332.5 kg triple superphosphate/ha. This amount should be added before planting of both rapeseed and maize.

Strategy for K: the STL is below the threshold and we need to add more K than that exported

K exported with rapeseed crop (no residues are exported, %K in harvest is 0.98):

3640 kg/ha x 0.0098 kg K/kg = 35.6 kg K/ha

K exported with maize crop (no residues exported, %K in harvest is 0.34):

12040 kg/ha x 0.0034 kg K/kg = 40.9 kg K/ha

Mean K export of rotation: 38.3 kg K/ha

With f_K=1.1 (sandy soil, Table 26.5)

$$K\ rate\ \left(kg\frac{P}{ha}\right) = Exported\ K + \frac{10\ \rho_b\ Z\ f_K}{N_{year}}\ (STL_t - STL)$$
$$= 38.3 + \frac{10\ x\ 1.5\ x\ 0.3x1.1}{2}\ (100-80)\ = 87.8\ kg\ K/ha$$

which may supplied with 87.8/0.415 = 211.6 kg potassium sulfate/ha. This amount should be added before planting of both rapeseed and maize.

Nitrogen fertilization

General equation (25.7, chapter 25)

$$N_f = \frac{N_{end} + (1 + f_{NR})\left(N_{yield} + N_{res}\right) - k_{im}\, F_{res}\, N'_{res} - f_{NR}\left(N'_{yield} + N'_{res}\right) - N_{other}}{(1 - n)}$$

Assumptions

N_{end} 10 kg/ha (lowest value in the range indicated in 25.2.3)

f_{NR} 0.2

k_{im} 0.7 (non legumes with tillage)

N_{other} 10 kg/ha (upper in range indicated in 25.2.3)

F_{res} 1 for both crops as all residues are incorporated

1-n 0.90 (we aim at a high efficiency)

Amount of N in yield and residues (take typical concentrations from Table 24.1)

Rapeseed N_{yield} = 3640 kg/ha x 0.039 kg N/kg = 142 kg N/ha

Rapeseed N_{res} = 7560 kg/ha x 0.008 kg N/kg = 60.5 kg N/ha

Maize N_{yield} = 12040 kg/ha x 0.016 kg N/kg = 192.6 kg N/ha

Maize N_{res} = 13307 kg/ha x 0.0097 kg N/kg = 129.1 kg N/ha

Rapeseed N fertilizer

$$N_f = \frac{10 + (1 + 0.2)(142 + 60.5) - 0.7 \cdot 129 - 0.2\,(192.6 + 129) - 10}{0.90}$$
$$= 98\ kg\ N/ha$$

Which may be supplied with 98/0.46= 213 kg urea/ha

Maize fertilizer

$$N_f = \frac{10 + (1 + 0.2)(192.6 + 129) - \ 0.7 \ \cdot 60.5 - 0.2\ (142 + 60.5) - \ 10}{0.9}$$

$$= 337\ kg\ N/ha$$

Which may be supplied with 337/0.46 = 732 kg urea/ha