OPTI-OAT

Oat Growth Guide

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Version 2019.01

Introduction

Demand for high quality UK oats for food use continues to increase, but research has indicated that there is a yield gap of approximately 4 t/ha between average and best on-farm oat yields.

To ensure growers and agronomists have the best available information, a UK consortium of leading industry and academic partners came together to form the Opti-Oat project. Under the leadership of PepsiCo and with co-funding from Innovate UK and BBSRC this project has developed the first UK Oat Growth Guide.

This Oat Growth Guide is designed to increase understanding of winter and spring oats through crop growth and development benchmarks, with the aim of improving yield and quality to deliver a sustainable supply and maximise grower returns.

Industry partners:

PEPSICO
James Hutton Limited
Impact through Science
Environment Systems

Academic partners and major subcontractors:

1872 Prifysgol Aberystwyth University
The James Hutton Institute
NIAB
ADAS

Co-funded by:

Innovate UK
BBSRC bioscience for the future

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Version 2019.01

Managing Oat Crops

Key points

- To manage a crop, a cycle of setting targets, assessment, adjustment and monitoring is needed
- The Oat Growth Guide is designed to provide benchmarks that can be used to monitor the success of crop management to achieve good yields
- The Oat Growth Guide is not designed to give advice on individual management decisions

Benchmarks

The benchmarks in this guide give numerical values against which oat crops can be compared. The benchmarks are indicated throughout the guide by the symbol on the right. These values are associated with high-yielding crops but should not necessarily be considered targets as they can vary according to situations, and a similar yield could be achieved in different ways. However, growers could use them as a tool for crop improvement as follows:

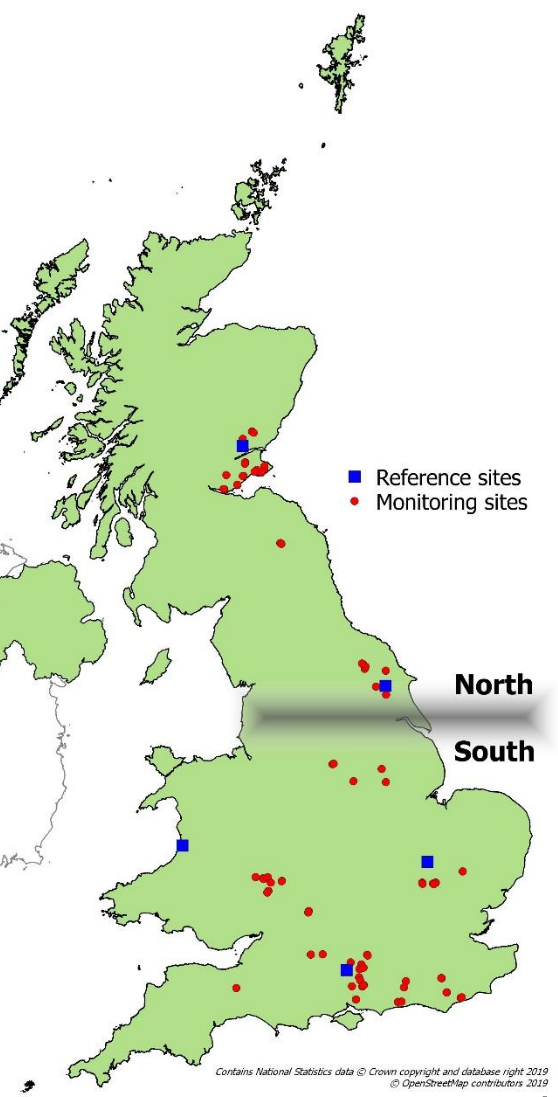
Set targets ➢ Assess progress against benchmarks ➢ Modify husbandry, where possible, to meet targets ➢ Re-assess crop progress & performance ➢ Adjust future crop management

Developing the benchmarks

The benchmarks in this guide were developed using data from experiments carried out in England, Scotland and Wales over four growing seasons (harvest 2014-2017). These ‘reference’ trials examined winter and spring husked milling oat varieties. The trial sites are represented by the blue squares on the map displayed on the right.

The benchmarks for winter and spring oats are presented in separate sections of this guide. Where the data indicate different crop performance in different regions of the UK (North vs South), benchmarks are displayed separately.

In addition to the intensively-measured ‘reference’ experiments, commercial fields of **Mascani** (70 fields) and **Canyon** (47 fields) were also monitored across four years (locations represented by the red symbols on the map). Key data from these fields are displayed throughout the guide where appropriate.



Winter oats (dark green page headers)

The benchmarks in the winter oats section of the guide are associated with a cv. **Mascani** crop yielding 8.0 t/ha at 15% moisture.

The dwarf variety **Balado** was also monitored and comparative data for this variety are displayed where there are relevant differences to Mascani.

Spring oats (light blue page headers)

The benchmarks in the spring oats section of the guide are associated with a cv. **Canyon** crop yielding 6.5 t/ha at 15% moisture.

Growth Stages

All Growth Stages used throughout are based on the Decimal Code System developed by Zadoks *et al* (1974).

Stage	Decimal code	Oat Growth Stage
Seedling growth	GS10	First leaf through coleoptile
	GS11	First leaf unfolded
	GS15	5 leaves unfolded
	GS19	9 or more leaves unfolded
Tillering	GS20	Main shoot only
	GS21	Main shoot and 1 tiller
	GS25	Main shoot and 2 tillers
	GS29	Main shoot and 9 or more tillers
Stem elongation	GS30	Inflorescence at 1cm (pseudostem erect)
	GS31	First node detectable
	GS32	2nd node detectable
	GS35	5th node detectable
	GS37	Flag leaf just visible
	GS39	Flag leaf blade all visible
'Booting'	GS41	Flag leaf sheath extending
	GS43	Flag leaf sheath just visibly swollen
	GS45	Flag leaf sheath swollen
	GS47	Flag leaf sheath opening
Panicle Emergence	GS51	First spikelet of panicle just visible
	GS55	Half of panicle emerged
	GS59	Panicle completely emerged
Flowering	GS61	Start of flowering
	GS65	Half-way through flowering
	GS69	Flowering complete
Milk development	GS71	Grain watery ripe
	GS73	Early milk
	GS75	Medium milk
	GS77	Late milk
Dough development	GS83	Early dough
	GS85	Soft dough
	GS87	Hard dough
Ripening	GS91	Grain hard (difficult to divide)
	GS92	Grain hard (not dented by nail)

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Winter Oats

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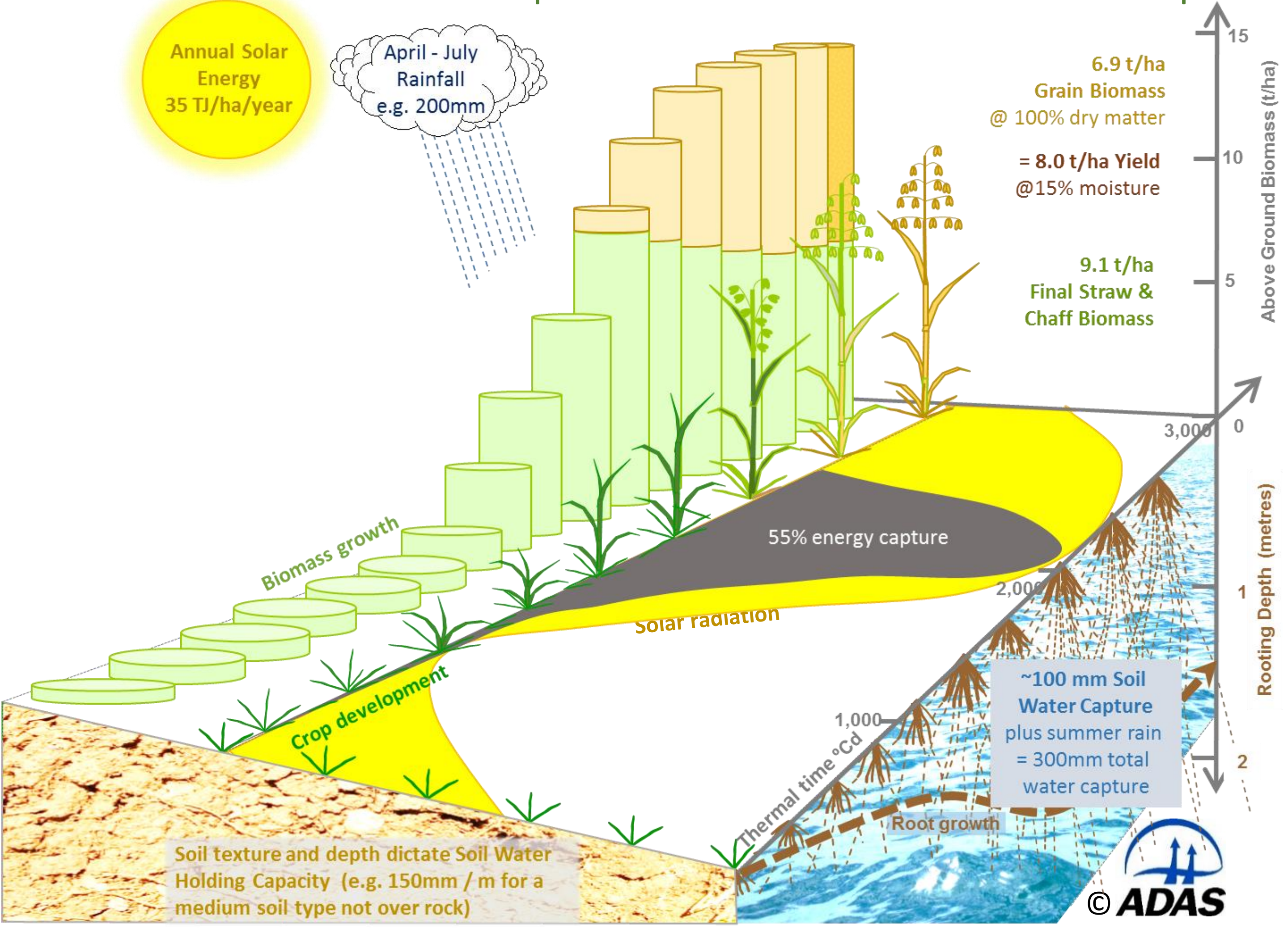
Resource Capture for Growth and Yield

Key points

- Oats, like other crops, grow through the capture and conversion of solar energy, water and carbon dioxide
- Oat yields can be improved through managing crops for increased resource capture
- The benchmark winter oat crop described in this guide captures 55% of available solar energy

Resource capture for a benchmark winter oat crop



Yield from Natural Resources

The yields of crops are determined by the amount of available **resources**, the proportion that is **captured** by the crop and their **conversion** to grain. Oats capture and utilise **solar energy**, **water**, and **carbon dioxide**. Solar energy and water resources vary by geographic location, but this cannot be controlled. Therefore, yields must be increased through **resource capture**. **Light capture** can be improved through increasing canopy cover and/or longevity. **Water capture** is mainly dependent on soil factors and root system volume and depth.

Potential Oat Yields

Potential yields can be calculated using figures of average available resources (solar radiation and water) in the UK. Assuming it is possible to maximise their capture through crop management and conversion using an optimised variety, theoretical potential oat yields are around 20 t/ha.

Oat Growth and Development

Key points

- **Growth**: Increase in a crop's overall size or weight
- **Development:** Changes in a crop's structure; Measured as progress through growth stages
- Growth is affected by individual management decisions, whereas development is altered by variety choice

Growth

Growth depends on incident light, canopy size and the capacity of the crop to capture and utilise light, and store dry matter. There is three-fold more growth on sunny days than cloudy days, because clouds cut out about two-thirds of the sun's energy.

Growth can be managed by optimising green canopy size. This can be achieved by modifying management practices throughout the season e.g. seed rate, nutrition, disease control and application of plant growth regulators.

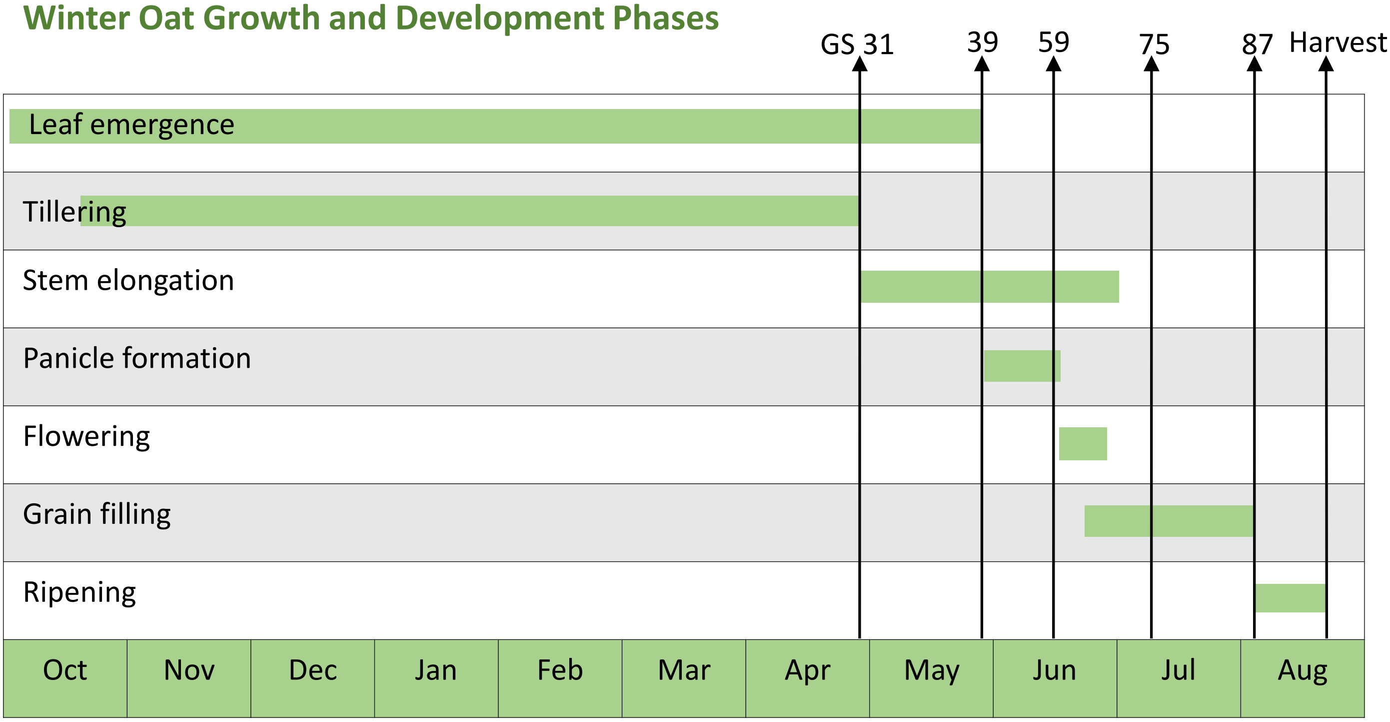
Development

Development is measured as progress through growth stages and can only be altered by variety and sowing date. The rate of development is affected by:

1. Temperature – warmer temperatures lead to a greater rate of development
2. Day length – longer days advance floral development

Winter oats generally require a period of cold (vernalisation) to induce flowering. However, unlike winter wheat, this is not an obligate requirement, so winter oat varieties that are not vernalised will flower eventually.

Winter Oat Growth and Development Phases



WO Benchmarks at Key Growth Stages

GS30: Inflorescence at 1cm	Mean	North	South
Date of GS	**11 Apr**	**16 Apr**	**07 Apr**
Above ground biomass (t/ha)	3.0	1.8	3.1
GAI	2.0	1.8	2.1

GS31: 1st node detectable	Mean	North	South
Date of GS	**24 Apr**	**08 May**	**15 Apr**
Above ground biomass (t/ha)	4.6	4.1	5.1
N uptake (kg/ha)	91	86	95
Shoots/m^2	640	680	600
GAI	3.6	3.7	3.4
Height (cm)	17	12	22

GS39: Flag leaf emerged	Mean	North	South
Date of GS	**24 May**	**01 Jun**	**18 May**
Above ground biomass (t/ha)	8.7	8.8	8.6
N uptake (kg/ha)	135	115	150
Shoots/m^2	550	605	490
GAI	6.2	6.2	6.1
Height (cm)	45	44	45

GS59: Panicle emerged	Mean	North	South
Date of GS	**12 Jun**	**18 Jun**	**08 Jun**
Above ground biomass (t/ha)	11.3	11.5	11.1
N uptake (kg/ha)	155	150	160
Shoots/m^2	430	430	430
GAI	6.8	6.6	6.9
$Height_a$ (cm)	65	60	69
$Height_b$ (cm)	85	79	91

GS75: Milky ripe	Mean	North	South
Date of GS	**06 Jul**	**10 Jul**	**03 Jul**
Above ground biomass (t/ha)	17.0	15.7	18.3
N uptake (kg/ha)	185	170	200
Shoots/m^2	415	395	430
GAI	4.7	5.1	4.3
$Height_a$ (cm)	67	63	71
$Height_b$ (cm)	97	95	98

GS87: Hard dough	Mean	North	South
Date of GS	**01 Aug**	**16 Aug**	**21 Jul**
Above ground biomass (t/ha)	15.9	15.6	16.2
N uptake (kg/ha)	205	180	230

Harvest	Mean	North	South
Date of Harvest	**18 Aug**	**23 Aug**	**15 Aug**
Grain yield (t/ha @ 85% moisture content)	8.1	8.2	8.0
Harvest index (%)	44	42	45
TGW (g @ 100% DM)	35.1	36.5	33.6

N.B. $Height_a$ (height to leaf ligule)
$Height_b$ (height to top of panicle)

Establishment

Key points

- Establishment is determined by germination, emergence and overwinter survival
- Adequate soil moisture, temperatures over 0°C and good aeration are required for germination
- Soil temperature and sowing depth affect emergence
- Oats are more susceptible to winter-kill than other cereals

Seed Rates and Plant Populations

Seed rates should be calculated based on the target spring plant population (approx. 250 plants/m²), the thousand grain weight of the seed being drilled and the percentage establishment, based on local conditions. Oats have potential to compensate for low plant population through increased tillering and the development of more grains per panicle.

$$\text{Seed rate} = \frac{\text{Target spring population x TGW}}{\text{Expected establishment}}$$

Spring population Mean = **210 plants/m²**
North = **200 plants/m²**
South = **218 plants/m²**

Germination and Emergence

Soil moisture, and good seed-soil contact, are required for germination. However where soil is very wet, aeration becomes limiting and can reduce germination. A minimum accumulation of temperature is required to reach specific growth stages. This is measured using thermal time (°C days), the accumulated mean daily temperature from sowing. As daily temperatures decline in autumn, it takes longer to accumulate the required thermal time and so takes longer for crops to emerge.

Thermal time to full emergence = 365 °C days

	Thermal time from sowing (°C days)	Plants/m²
Mean	365	235
North	390	225
South	340	240

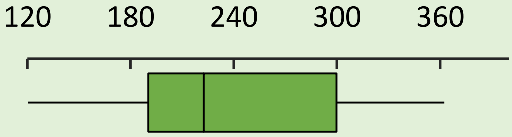
Overwinter Survival

Oats are the least winter hardy of all the cereals and are susceptible to plant loss in cold winters. Overwinter survival is site dependent, but seedbed consolidation can reduce the risk of frost heave.

Overwinter survival: Mean = **88 %** North = **91%** South = **86%**

Median (with range) of plant numbers established in monitored commercial Mascani crops

Plants/m² established post winter



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Tillering and Shoot Survival

Key points

- Tillering is important in determining canopy development and yield
- Seed rates and nitrogen influence tiller numbers
- Temperature controls the rate of leaf emergence

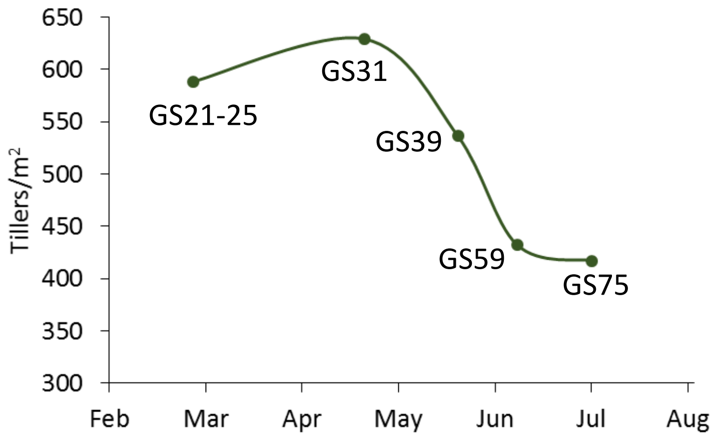
Leaf Emergence

The first leaf emerges from the coleoptile soon after drilling. Leaves then emerge continuously on main stems and tillers until the final (flag) leaf emerges. The rate of leaf emergence is referred to as the phyllochron. This is affected by temperature and is measured using thermal time (°C days). The phyllochron of oats measured in the Opti-Oat project trial was 145 °C days.

Tillering

Tillering starts when a few leaves have emerged and continues until the start of stem extension. Tillering is affected by seed rate, temperature and the availability of water and nutrients. Applying N before stem extension generally increases tillering whereas applying N later can improve tiller survival.

Progress of Tillering



Shoot number at GS31
Mean = 640/m²
North = **680/m²**
South = **600/m²**

Final shoot number
Mean = 415/m²
North = **395/m²**
South = **430/m²**

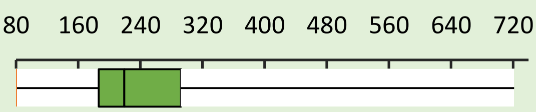
Dwarf oats (Balado)
The final shoot number for dwarf oats was 315/m².

Shoot Survival and Final Shoot Numbers

Maximum shoot number almost always exceeds final shoot number. Smaller, later–formed tillers die off as competition for light and nitrogen increases throughout the season. In the South, a higher proportion of tillers survive than in the North.

Median (with range) of tiller numbers in monitored commercial Mascani crops

Tillers/m² pre harvest



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Nitrogen Uptake

Key points

- Oats are often grown after other cereal crops so soil nitrogen (N) is generally low
- N fertiliser is required to manage canopy size throughout the season, usually over a number of applications

Sources of Nitrogen

i) Soil

The amount of soil nitrogen available to an oat crop is generally low due to the fact they often follow a cereal crop. Typically around 20-40 kg/ha of available N (nitrate and ammonium) is supplied by the soil. It is increased by unrecovered fertiliser residues from previous crops or organic residues.

Release of soil N and crop recovery are both variable. Release is stimulated in warm, moist soils and after cultivations that thoroughly disturb the soil and uptake continues throughout growth. Nitrogen uptake can be improved by early sowing and unimpeded rooting.

ii) Fertiliser

Fertiliser N stays in the surface throughout the season and is partly (~30-60%) immobilised during stem extension. The ~40-70% taken up is generally acquired at a constant rate, independent of the amount applied, and so is taken up for longer, the more that is applied. Some uptake continues after flowering, either from N residues at depth, or from mineralisation of the recently immobilised fertiliser N, depending largely on moisture conditions.

Canopy Nitrogen Requirements

An oat crop's canopy is highly influenced by N uptake. N uptake affects canopy size by promoting tillering before stem extension, shoot survival during stem extension and prolonged survival of yield-forming leaves after stem extension. Canopy size is referred to as Green Area Index (GAI) which is a measurement of the green area of the crop compared to the ground area it occupies.

The area of the crop's green tissues relates to the amount of N they contain; there are about 24 kg N per hectare of green tissue. This means it's possible to control canopy size by controlling N availability.

N uptake = 24 kg/ha/GAI unit (average N uptake per unit of GAI GS31-59)

Nitrogen uptake throughout the season for Mascani

N taken up to GS31	GS31-39	GS39-59
		
Rate = 0.5 kg/ha/day	= 1.4 kg/ha/day	= 1.0 kg/ha/day
Total = 92 kg/ha by GS31	= 134 kg/ha by GS39	= 154 kg/ha by GS59

Green Area Index (GAI) is a measurement of the green area of crop compared to the ground area it occupies

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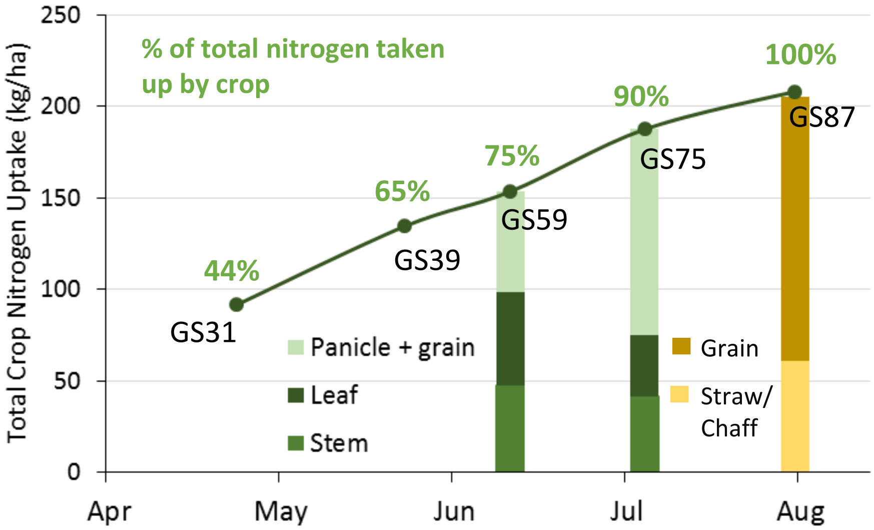
Nitrogen Uptake

Pattern of N uptake

Nitrogen uptake is low through the winter but speeds up from mid-March when the warmer weather accelerates canopy expansion and tillering. Between GS31 and 39, the rate of N uptake is at its greatest as the crop canopy size increases. Uptake slows down after GS39 when the crop moves into panicle formation.

By GS87, a benchmark crop takes up 205 kg N/ha.



N partitioning (kg/ha)

	GS59	*GS75*	*GS87*
Stem	48	41	-
Leaf	51	34	-
Panicle	55	113	-
Grain	-	-	144
Straw/ chaff	-	-	61

N redistribution to grain

There is a significant redistribution of N within the crop during grain-filling; proteins in leaves are degraded and N is transferred up the plant to form grain protein. This, rather than root uptake, is the main source of grain N during grain-filling.

At GS87, straw and chaff contain 61 kg N/ha, 93 kg/ha less than at GS59.

Total N in crop at harvest = 205 kg/ha
of which grain = 70 %
straw/chaff = 30 %

Total crop N content (kg/ha) of monitored commercial Mascani crops

	Start stem extension	Flowering	Mid grain-fill
Nitrogen (kg/ha)	90	110	120

Canopy Expansion and Senescence

Key points

- Canopy size is determined by leaf and tiller numbers
- Oats often develop a greater green area index than wheat or barley
- To maximise yield, canopies need to be managed, both during expansion and senescence.

The canopy of an oat crop includes all the green components; leaves, stems and panicles. Leaves make up the largest proportion of the total green area.

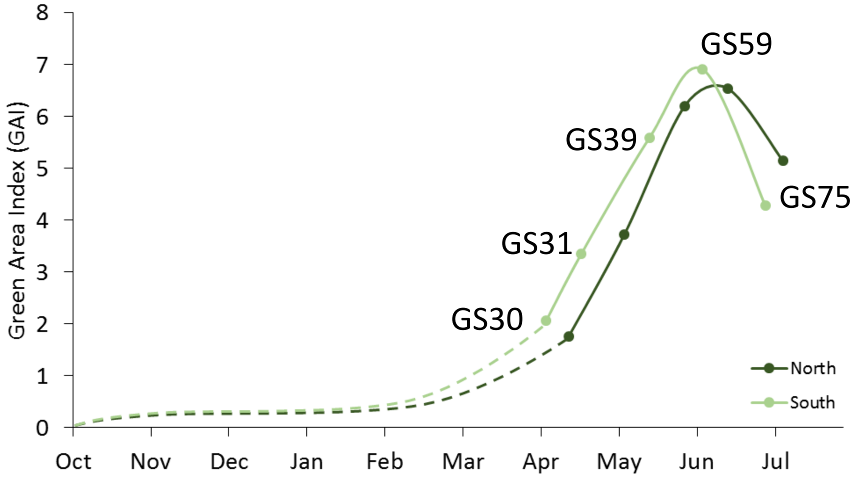
Canopy size is referred to as Green Area Index (GAI) which is a measurement of the green area of the crop compared to the ground area it occupies.

This crop has a GAI of 2, i.e. there is 2m^2 of green canopy per 1m^2 soil

Canopy Expansion

Growth is slower over the winter period so the canopy expands slowly between drilling and GS30.

Between GS31 and GS39 canopy expansion is at its most rapid, with GAI increasing by 1 unit every 11-12 days. GAI peaks at GS59, then starts to decrease between GS59 and GS75 as the canopy senesces.



GAI at GS31 = 3.6
North = **3.7**
South = **3.4**

GAI at GS39 = 6.2
North = **6.2**
South = **6.1**

GAI at GS59 = 6.8
North = **6.6**
South = **6.9**

As the canopy becomes thicker each unit of GAI intercepts proportionally less light energy.

Canopy Senescence

Green area loss generally starts at GS59 when lower leaves start to die. Between GS59 and GS75 GAI reduces by 1 unit every 11-12 days.

GAI at GS75 = 4.7 North = **5.1** South = **4.3**

GAI of monitored commercial Mascani crops

	Start stem extension	Flowering
GAI	3.1	4.5

Biomass Gain

Key points

- Growth is measured by the increase in crop dry matter
- Growth is slow before GS31 but rapid between GS31 and GS75
- Dry weight gain slows and may decrease after GS75 when the canopy has senesced significantly

Growth up to GS31

Growth is slow up to GS31 with only 30% of the crop's total dry matter formed during that period.

Biomass accumulated by GS31 Mean = **4.6 t/ha**
North = **4.1 t/ha**
South = **5.1 t/ha**

Rapid Dry Matter Accumulation

After GS31, the crop accumulates biomass rapidly for a period of 11 weeks with over 75% of the total dry matter formed during this period.

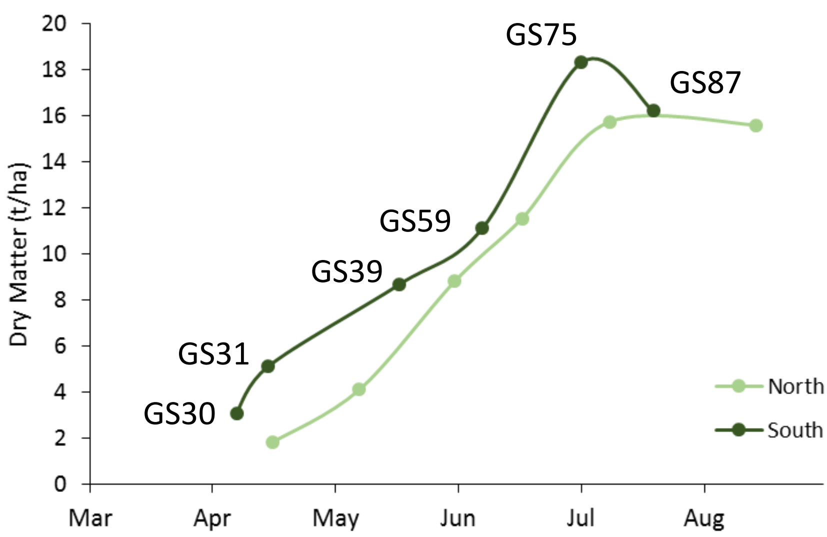
During this time, the crop intercepts 65% of the light captured over the whole season.

Growth during rapid expansion period (GS31 – GS75) = 0.2 t/ha/day

Stem Reserves

Soluble stem reserves build up and reach a maximum (2.5 t/ha) around GS59. During grain filling these are redistributed from the leaves and stems to the grains and buffer the crop against poor growing conditions.

Change in Crop Dry Weight Over the Growing Season



Dwarf oats (Balado)

Dry matter (t/ha):

	Mean	North	South
GS30	2.2	1.5	2.7
GS31	4.5	3.8	4.8
GS39	8.2	8.2	8.3
GS59	12.5	11.1	14.6
GS75	16.1	14.5	17.4
GS87	17.1	16.6	17.4

Crop biomass (t/ha) of monitored commercial Mascani crops

	Start stem extension	Flowering	Mid grain-fill
Biomass (t/ha)	4.5	9.5	14.7

Stem Extension and Final Height

Key points

- There are two distinct types of oat varieties – conventional and dwarf, which differ significantly in their height
- As well as variety, height is affected by environmental and management factors
- Lodging control is an important aspect of the management of conventional oats

Height of Oats

There are two distinct types of oat varieties – conventional and dwarf, and these differ significantly in their height, with dwarf varieties generally 15-20 cm shorter than conventional varieties. For consistency, the heights quoted in this guide are measured to the flag leaf ligule unless otherwise stated.

Oat stems are typically made up of six internodes, with the internode below the peduncle at the top of the plant being the longest and those at the bottom of the stem the shortest. Stem extension starts at GS30 and the internodes continue to grow until final crop height is achieved at GS75.

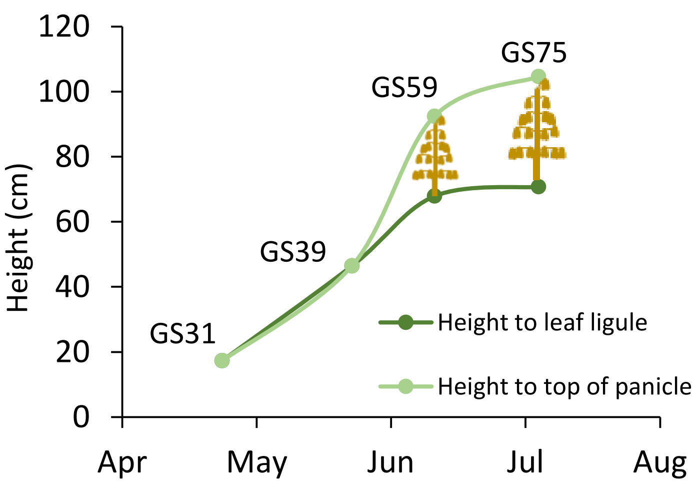
Panicle extrusion varies between crops, varieties and variety types. Generally, the taller the oat cultivar, the better the panicle extrusion.

Final height (top of panicle) — **Mean = 97 cm**; North = **95 cm**; South = **98 cm**

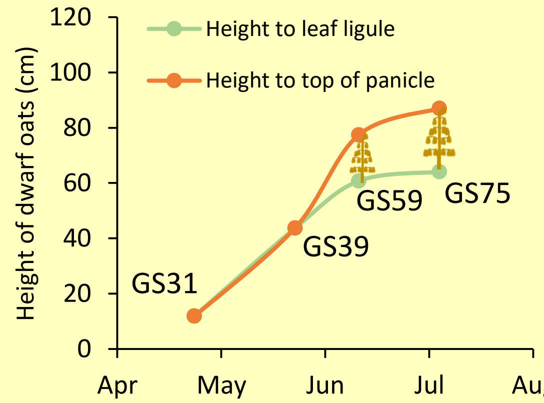
Lodging

Conventional height oats are seen as more prone to lodging than wheat and barley as oats are often taller than other cereals. However, more modern varieties are less prone to lodging as they have stronger, slightly shorter stems. Generally, oats do have thicker stems and stem walls and better anchorage strength (greater root plate width and depth) than wheat.

The Mascani crops grown in these reference trials received a robust programme of plant growth regulators (PGRs). Dwarf oats should not receive PGRs as this can make them taller. Oats can also be affected by brackling (buckling of the middle internodes). This doesn't usually affect yields or harvest, but can affect grain quality.



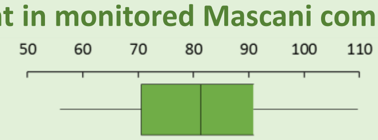
Dwarf oats (Balado) - No PGR applied



Final height (top of panicle) — **Mean = 87 cm**; North = **85 cm**; South = **89 cm**

Median (with range) of final height in monitored Mascani commercial crops

Height (cm) to top of panicle pre harvest



WO Panicle Formation and Grain Filling

Key points

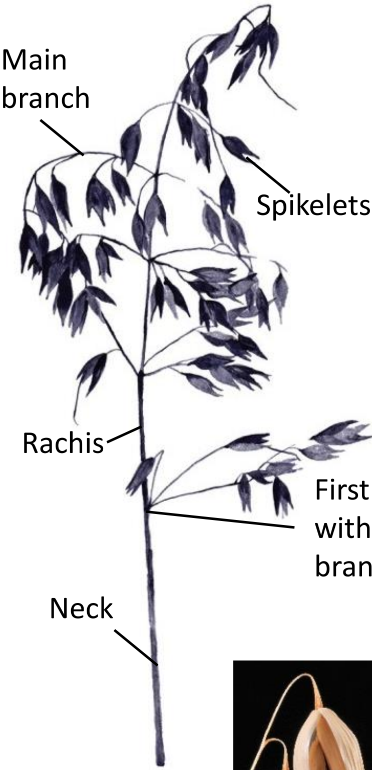
- Grain filling capacity is determined by the number of grains per panicle and grain size
- Potential grain number per panicle is determined before flag leaf emergence during spikelet initiation
- Grain filling determines final grain size, but grain number has a greater effect on final yield

Grain Number Determination

Oat grains develop in a panicle which has a number of branches (often ~4) radiating in whorls from 5-7 nodes on the central rachis. Oat spikelets are found at the end of small branches (pedicels) connected to the main branch. The spikelets contain 2-3 florets, each of which can produce a grain. The majority contain two grains which differ in size, giving a bimodal distribution of grain size. The number of spikelets per whorl decreases towards the top of the panicle, with around 75% of spikelets contained on the bottom 3 whorls.

In oats the lemma and palea, which contain the grain, remain attached to the grain at harvest as the husk. Grain yields and harvest indices include this husk.

Grains per panicle and panicles per m^2 are influenced by management practices. In oats, yield is more strongly related to grain number than grain size.




Oat spikelet containing 2 florets

Grains per panicle Mean = **47**
North = **42**
South = **51**

Panicle Weight

Panicle weight at harvest Mean = **2.4 g**
North = **2.2 g**
South = **2.6 g**

Dwarf oats (Balado)

	Mean	North	South
Grains per panicle	66	60	69
Panicle weight at harvest (g)	3.5	3.4	3.6

Grain Filling and Ripening

Photosynthesis and redistribution of stem reserves are both important for grain filling. Final grain dry weight, appearance and specific weight are all determined during grain filling. Grain ripening can take up to a further two weeks before the grain is at an appropriate moisture content to harvest (ideally not greater than 15% moisture content).

Final grain weight (TGW, 15% mc) Mean = **41.3 g**
North = **43.0 g**
South = **39.5 g**

Yield

Key points
- Grain yield is about half of the total biomass of the crop
- Panicle number per m^2 and grains per panicle determines final yield more than grain weight and size
- Dwarf oats make up their yield with more grains per panicle but fewer panicles per m^2

Grain Yield

Grain yield is made up of three components, of which grain weight is the most stable. Most differences in yield between sites and seasons reflect differences in grain number rather than grain weight.

Grain yield (15% mc): a product of	Panicles/m^2 and	Grains/panicle and	Average grain weight
8.1 t/ha	415	47	41.3 mg/grain

Harvest Index

Harvest Index is the ratio of grain to total above ground biomass. Harvest index varies relatively little between sites and seasons, but it does vary between variety types. These values are based on 100% dry matter.

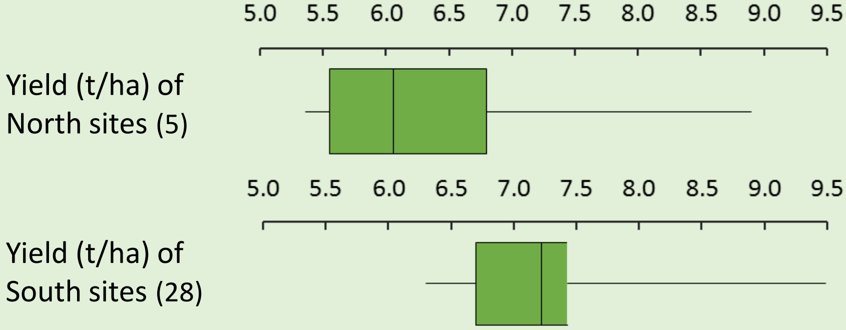
Total biomass at harvest = 16.0 t/ha
of which grain = 44 %
straw and chaff = 56 %

Grain Moisture
Moisture is the most important consideration in storage of food grade oats and is primarily determined by environmental factors. Grain should be dried to between 11% and 15% moisture before storage. Improper moisture control can result in the growth of micro-organisms and the loss of nutritional quality and the growth of micro-organisms that can cause spoilage.

Dwarf oats (Balado)

Grain yield (15% mc): a product of	Panicles/m^2 and	Grains/panicle and	Average grain weight
8.0 t/ha	315	66	38.5 mg/grain

Median (with range) of grower-reported yield in monitored commercial Mascani crops



Grain Quality

Key points

- As well as variety, crop nutrition strategies can impact grain quality traits in oats
- A lodged crop is associated with reduced grain quality

Specific Weight and Screenings

Grain specific weight is an indication of individual grain density. It is predominantly determined by plant variety genetics, and factors affecting length of the grain filling period. Poorly managed crop nutrition and lodging can reduce specific weight. Milling oats should have a minimum specific weight of 50 kg/hl, with a target of approximately 55 kg/hl.

Oat screenings consist of small and broken grains and are removed during the cleaning stage before oats are processed. If the screenings level is too high, it can reduce milling throughput, and so it is important to reduce screenings on farm.

Specific weight Mean = **53.5 kg/hl**
North = **54.3 kg/hl**
South = **53.1 kg/hl**

Screenings Mean = **2.0 %**
North = **0.8 %**
South = **2.2 %**

Kernel Content, Grain Protein and Beta-Glucan

Kernel content is proportion of harvested oats (husk + groat) that is made up of the kernels or groats. It is a highly heritable trait but is also influenced by management practices, particularly increased N application.

In oats, protein content is significantly affected by the crop nutrition strategy, particularly the timings and rates of nitrogen applied. Environmental factors and variety also have an impact.

Beta-glucan, a form of soluble dietary fibre found in oats, has been shown to lower blood cholesterol. Beta-glucan content in oats is mainly determined by environmental factors and variety.

In the Opti-Oat project, protein and beta-glucan content were measured on groats on a dry matter basis.

Grain protein Mean = **11.6 %**
North = **11.0 %**
South = **12.0 %**

Beta-glucan Mean = **3.9 %**
North = **3.7 %**
South = **4.0 %**

Kernel content Mean = **72.9 %**
North = **74.7 %**
South = **71.6 %**

Median (with range) for grain quality traits in monitored commercial Mascani crops

	North	South
Specific weight (kg/hl)	52.8 (51.8 – 53.7)	52.0 (50.7 – 54.0)
Screenings (%)	0.1 (0.0 – 0.4)	0.3 (0.0 – 0.4)
Grain protein (%)	14.0 (12.1 – 15.8)	13.2 (12.4 – 14.3)
Beta-glucan (%)	3.9 (3.7 – 4.2)	4.0 (3.7 – 4.4)
Kernel content (%)	73.5 (71.3 – 75.6)	72.2 (70.5 – 75.3)

SO

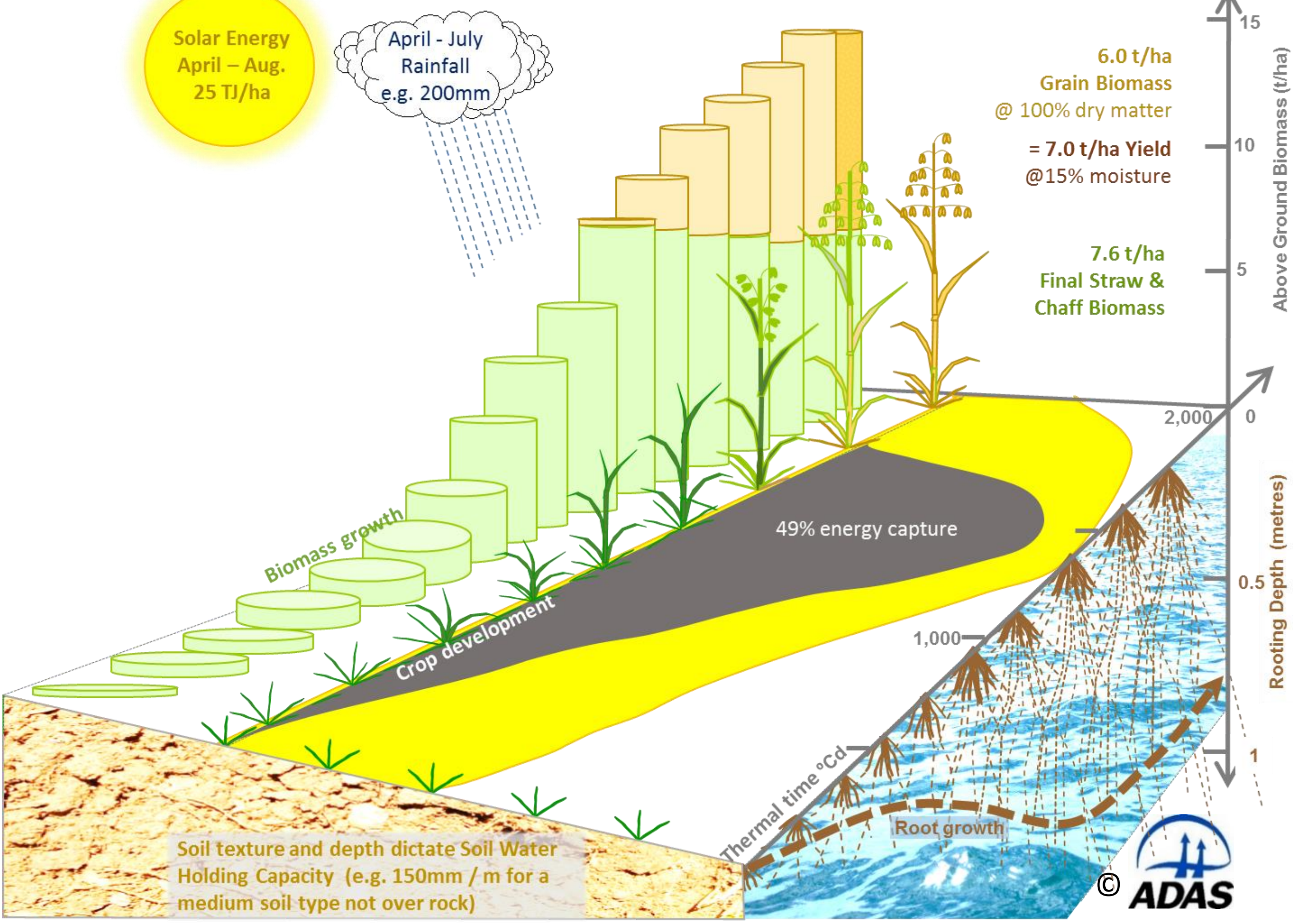
Spring Oats

Resource Capture for Growth and Yield

Key points

- Oats, like other crops, grow through the capture and conversion of solar energy, water and carbon dioxide
- The benchmark spring oat crop described in this guide captures 49% of available solar energy
- Oat yields can be increased through managing crops for increased resource capture

Resource capture for a benchmark spring oat crop



Yield from Natural Resources

The yields of crops are determined by the amount of available **resources**, the proportion that is **captured** by the crop and their **conversion** to grain.

Oats capture and utilise **solar energy**, **water**, and **carbon dioxide**. Solar energy and water resources vary by geographic location, but this cannot be controlled. Therefore, yields must be increased through **resource capture**. **Light capture** can be improved through increasing canopy cover. **Water capture** is mainly dependent on root growth.

Potential Oat Yields

Potential yields can be calculated using figures of average available resources (solar radiation and water) in the UK, and assuming it is possible to maximise their capture through crop management and conversion using an optimised variety. Theoretical potential oat yields are around 20 t/ha.

SO

Oat Growth and Development

Key points

- **Growth**: Increase in a crop’s overall size or weight
- **Development:** Changes in a crop’s structure; Measured as progress through growth stages
- Growth is affected by individual management decisions, whereas development is altered by variety choice

Growth

Growth depends on incident light, canopy size and the capacity of the crop to utilise light and store dry matter.

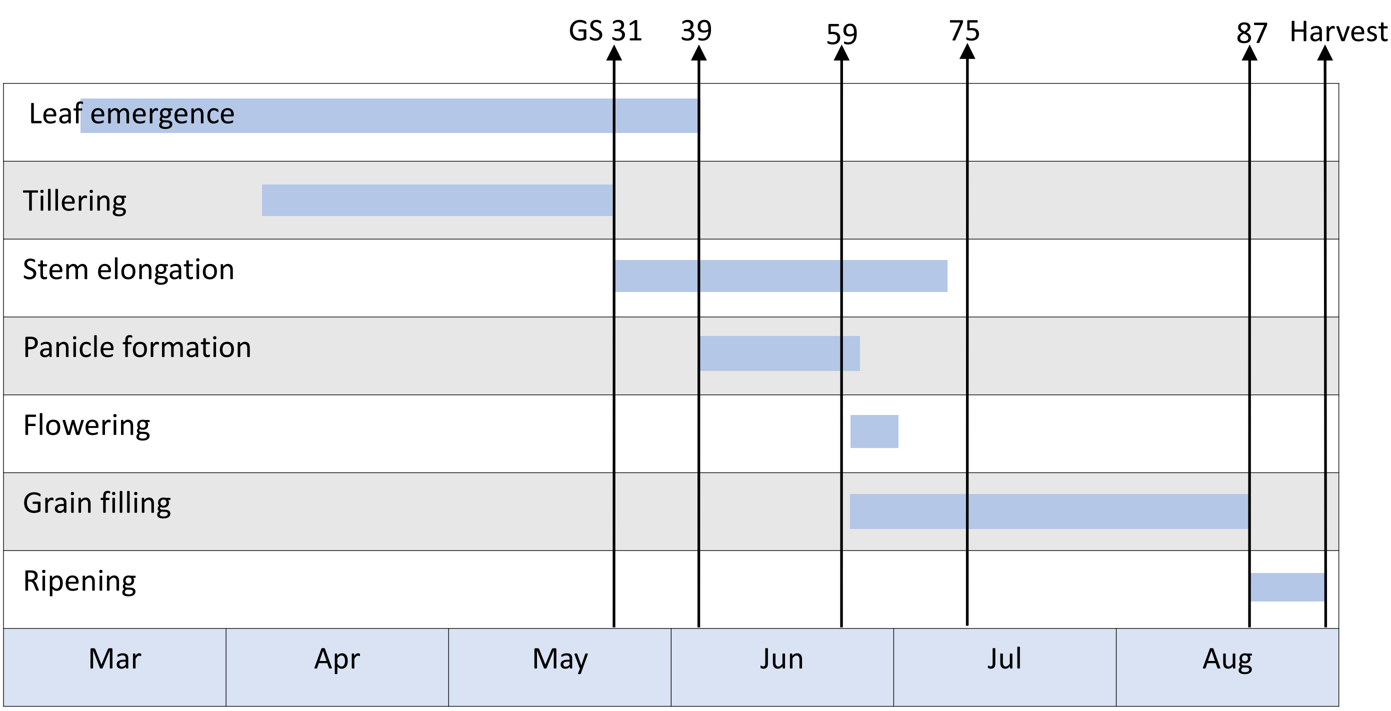
Growth can be managed by optimising green canopy size. This can be achieved by modifying management practices throughout the season e.g. nutrition, disease control and application of plant growth regulators.

Development

Development is measured as progress through growth stages and can only be altered by variety and sowing date. Development is affected by:

1. Temperature – warmer temperatures lead to a greater rate of development
2. Day length – longer days advance floral development

Spring Oat Growth and Development Phases



SO

Benchmarks at Key Growth Stages

GS 30: Inflorescence at 1cm	Mean	North	South
Date of GS	**15 May**	**21 May**	**10 May**
Above ground biomass (t/ha)	1.3	1.2	1.3
GAI	1.3	1.4	1.2

GS31: 1st node detectable	Mean	North	South
Date of GS	**22 May**	**31 May**	**17 May**
Above ground biomass (t/ha)	2.1	1.7	2.3
N uptake (kg/ha)	73	60	85
Shoots/m^2	445	455	435
GAI	2.1	1.8	2.3
Height (cm)	26	22	29

GS39: Flag leaf emerged	Mean	North	South
Date of GS	**04 June**	**08 June**	**01 June**
Above ground biomass (t/ha)	4.0	3.7	4.2
N uptake (kg/ha)	88	77	98
Shoots/m^2	425	420	425
GAI	3.0	2.8	3.2
Height (cm)	46	41	50

GS59: Panicle emerged	Mean	North	South
Date of GS	**23 June**	**28 June**	**18 June**
Above ground biomass (t/ha)	7.0	6.8	7.1
N uptake (kg/ha)	115	100	130
Shoots/m^2	350	335	370
GAI	4.0	3.5	4.4
Height$_a$ (cm)	70	70	69
Height$_b$ (cm)	91	86	96

GS75: Milky ripe	Mean	North	South
Date of GS	**10 July**	**20 July**	**05 July**
Above ground biomass (t/ha)	11.9	11.5	12.2
N uptake (kg/ha)	155	140	170
Shoots/m^2	370	380	355
GAI	3.1	2.8	3.3
Height$_a$ (cm)	73	74	72
Height$_b$ (cm)	108	110	105

GS87: Hard dough	Mean	North	South
Date of GS	**19 August**	**27 August**	**13 August**
Above ground biomass (t/ha)	12.6	13.3	11.9
N uptake (kg/ha)	160	155	165

Harvest	Mean	North	South
Date of Harvest	**27 August**	**05 Sept**	**20 August**
Grain yield (t/ha @ 85% moisture content)	7.0	7.1	6.9
Harvest index (%)	48	45	49
TGW (g @ 100% DM)	36.5	40.0	32.7

N.B. Height$_a$ (height to leaf ligule)
Height$_b$ (height to tip of panicle)

Establishment

Key points

- Establishment consists of germination and emergence
- Adequate soil moisture, temperature over 0°C and oxygen are needed for germination
- Soil temperature and sowing depth affects emergence

Seed Rates and Plant Populations

Seed rates should be calculated based on the target spring population (approx. 275 plants/m^2), the thousand grain weight of the seed being drilled and the percentage establishment, based on local conditions. Oats have potential to compensate for low plant population through increased tillering and the development of more grains per panicle.

$$\text{Seed rate} = \frac{\text{Target spring population x TGW}}{\text{Expected establishment}}$$

Population = 260 plants/m^2

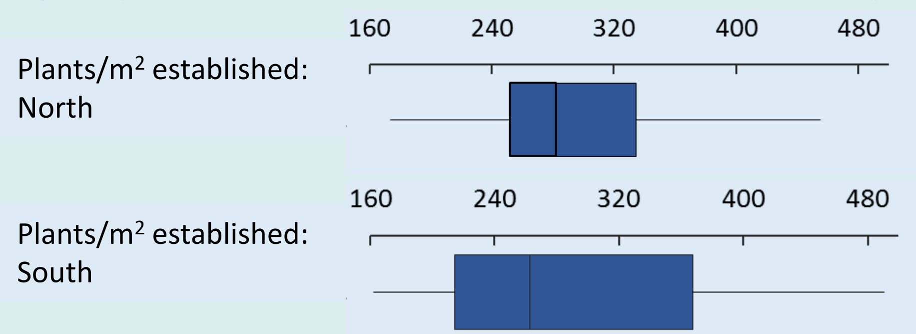
Germination and Emergence

Soil moisture and good seed:soil contact is required for germination. However where soil is very wet, oxygen becomes limiting which can reduce germination. A minimum accumulation of temperature is required to reach specific growth stages. This is measured using thermal time (°C days), the accumulated mean daily temperature from sowing.

	Thermal time from sowing (°C days)	Plants/m^2
Average	316	260
North	320	270
South	312	250

Thermal time to full emergence = 316 °C days

Median (with range) of plant numbers established in monitored commercial Canyon crops



Tillering and Shoot Numbers

Key points
- Tillering is affected by temperature
- Final shoot number is an important component of yield

Leaf Emergence

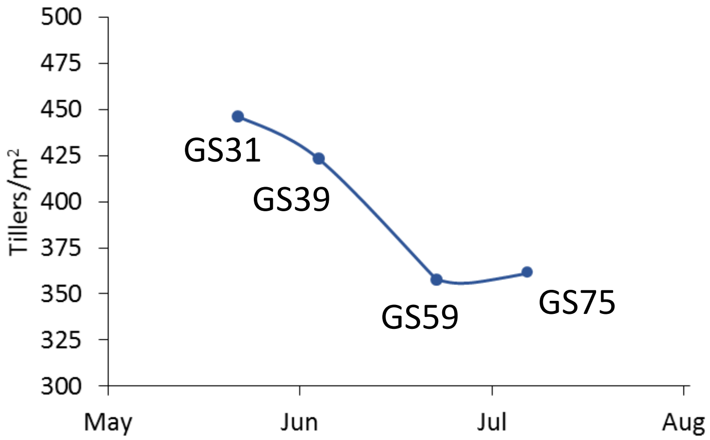
The first leaf emerges from the coleoptile soon after drilling. Leaves then emerge continuously on main stems and tillers until the final (flag) leaf emerges. The rate of leaf emergence is referred to as the phyllochron. This is affected by temperature and is measured using thermal time (^oC days). The phyllochron of oats measured in the Opti-Oat project trial was 145 ^oC days.

Tillering

Tillering starts when a number of leaves have emerged, and continues until the start of stem extension.

Tillering is affected by seed rate, temperature and the availability of water and nutrients. Applying N before stem extension can increase tiller numbers.

Progress of Tillering



Shoot numbers at GS31
Mean = 445/m²
North = **455/m²**
South = **435/m²**

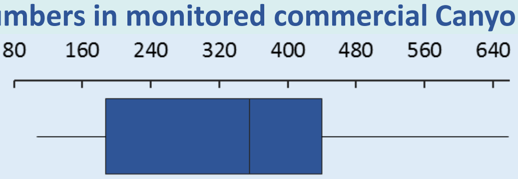
Final shoot number
Mean = 370/m²
North = **380/m²**
South = **355/m²**

Final Shoot Numbers

Maximum shoot number almost always exceeds final shoot number. Smaller, later–formed tillers die off as competition for light and nitrogen increases throughout the season.

Median (with range) of tiller numbers in monitored commercial Canyon crops

Tillers/m² pre harvest



Nitrogen Uptake

Key points
- Oats are often grown after other cereal crops so soil nitrogen (N) is generally low
- N fertiliser is required to manage canopy size through the season, usually over a number of applications

Sources of Nitrogen

i) Soil

The amount of soil nitrogen available to an oat crop is often low due to the fact they often follow a cereal crop. Typically 20-40 kg/ha of available N (nitrate and ammonium) is supplied by the soil. This is increased by unrecovered fertiliser residues from previous crops or organic residues.

Release of soil N and crop recovery are both variable. Release is stimulated in warm, moist soils and after cultivations that thoroughly disturb the soil and uptake continues throughout growth. Nitrogen uptake can be improved by early sowing and unimpeded rooting.

ii) Fertiliser

Fertiliser N stays in the surface throughout the season and is partly (~30-60%) immobilised during stem extension. The ~40-70% taken up is generally acquired at a constant rate, independent of the amount applied, and so is taken up for longer, the more that is applied. Some uptake continues after flowering, either from N residues at depth, or from mineralisation of the recently immobilised fertiliser N, depending largely on moisture conditions.

Canopy Nitrogen Requirements

An oat crop's canopy is highly influenced by N uptake. N uptake affects canopy size by promoting tillering before stem extension, shoot survival during stem extension and prolonged survival of yield-forming leaves after stem extension. Canopy size is referred to as Green Area Index (GAI) which is a measurement of the green area of the crop compared to the ground area it occupies.

The area of the crop's green tissues relates to the amount of N they contain; there are about 24 kg N per hectare of green tissue. This means it's possible to control canopy size by controlling N availability.

N uptake = 45 kg/ha/GAI unit

Nitrogen uptake throughout the season for Canyon

N taken up to GS31

Rate = 1.2 kg/ha/day
Total = 74 kg/ha by GS31

GS31-39

= 1.0 kg/ha/day
= 88 kg/ha by GS39

GS39-59

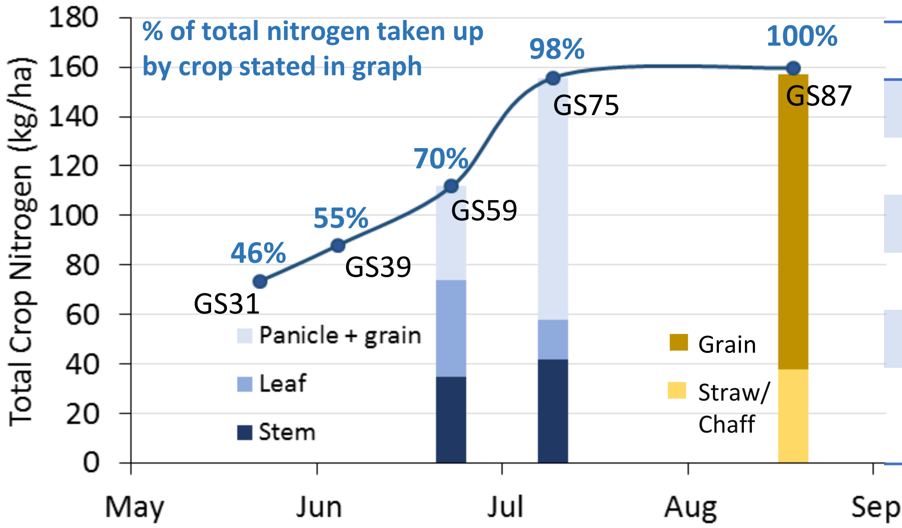
= 1.3 kg/ha/day
= 112 kg/ha by GS59

Version 2019.01

Pattern of N uptake

In spring oats, the rate of nitrogen uptake is consistent up to GS59. As the crop is sown in warmer spring conditions, growth and N uptake can start rapidly.

By GS87, a benchmark crop takes up 157 kg N/ha.



N partitioning (kg/ha)

	GS59	*GS75*	*GS87*
Stem	35	42	-
Leaf	40	16	-
Panicle	38	98	-
Grain	-	-	119
Straw/ chaff	-	-	38

N redistribution to the grain

There is a significant redistribution of N within the crop during grain-filling; proteins in leaves are degraded and N is transferred up the plant to form grain protein. This, rather than root uptake, is the main source of grain N during grain-filling.

At GS87, straw and chaff contain 38 kg N/ha, 75 kg/ha less than at GS59.

Total N in crop at harvest = 157 kg/ha
of which grain = 76 %
straw/chaff = 24 %

Crop Nitrogen (kg/ha) of monitored commercial Canyon crops

	Start stem extension	Flowering	Mid grain-fill
Nitrogen (kg/ha)	59	112	140

Canopy Expansion and Senescence

Key points

- Canopy size is determined by leaf and tiller numbers
- Oats often develop a greater green area index than wheat or barley
- To maximise yield, canopies need to be managed during both expansion and senescence

The canopy of an oat crop includes all the green components; leaves, stems and panicles. Leaves make up the largest proportion of the total green area.

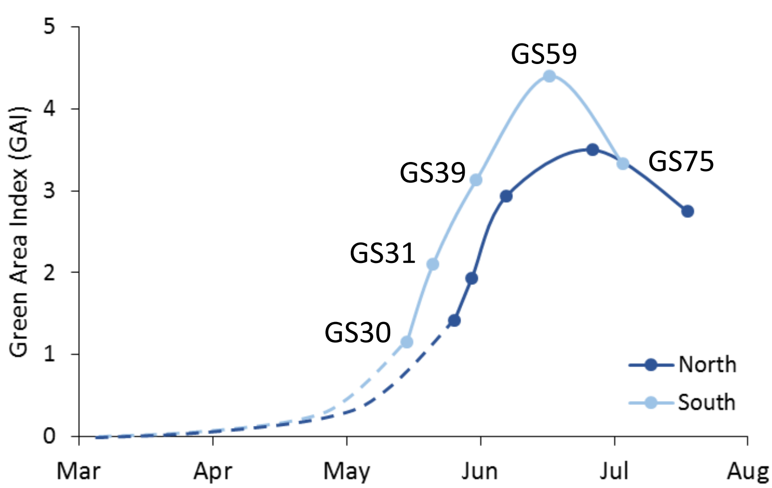
Canopy size is referred to as Green Area Index (GAI) which is a measurement of the green area of the crop in relation to the ground area it occupies.

This crop has a GAI of 2, i.e. there is $2m^2$ of green canopy per $1m^2$ soil.

Canopy Expansion

The canopy expands slowly from drilling until GS31 as growth is slow.

Between GS31 and GS39 expansion is at it's most rapid, with GAI increasing by 1 unit every 11-12 days. GAI peaks at GS59, then starts to decrease between GS59 and GS75 as canopy senescence occurs.



GAI at GS31 = 2.1
North = **1.8**
South = **2.3**

GAI at GS39 = 3.0
North = **2.8**
South = **3.2**

GAI at GS59 = 4.0
North = **3.5**
South = **4.4**

As the canopy becomes thicker each unit of GAI intercepts proportionally less light energy.

Canopy Senescence

Green area loss becomes more rapid after GS59 as the leaves senesce, with lower leaves dying off first. Between GS59 and GS75 GAI reduces by 1 unit every 16-17 days

GAI at GS75 = 3.1 North = **2.8** South = **3.3**

GAI of monitored commercial Canyon crops

	Start stem extension	Flowering
GAI	1.7	3.0

Biomass Gain

Key points

- Growth is measured by increase in crop dry matter
- Growth is slow before GS31 but rapid between GS31 and GS75
- Dry weight gain only slows after GS75 when the canopy has senesced significantly

Growth up to GS31

Growth is slow up to GS31 with only 30% of the crop's total dry matter formed during that period.

Biomass accumulated by GS31 Mean = **2.1 t/ha**
North = **1.7 t/ha**
South = **2.3 t/ha**

Rapid dry matter accumulation

After GS31, the crop accumulates biomass rapidly for a period of approximately 7 weeks and over 78% of the total dry matter is formed during this period.

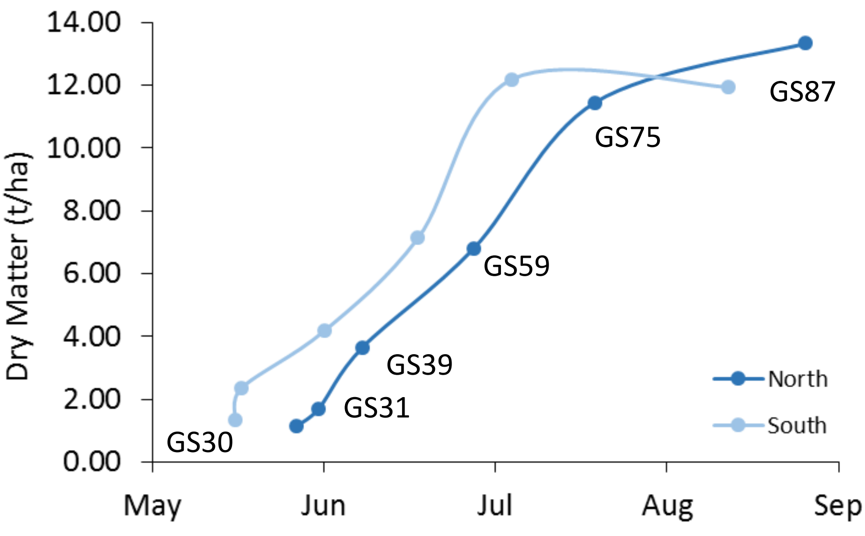
During this period the crop intercepts over 63% of the total light captured during the season.

Growth during rapid expansion period (GS31 – GS75) = 0.2 t/ha/day

Stem reserves

Soluble stem reserves build up and reach a maximum (0.89 t/ha) around GS59. During grain filling these reserves are redistributed from the leaves and stems to the grains in the panicles to buffer the crop against poor growing conditions.

Change in crop dry weight over the growing season



Crop biomass (t/ha) of monitored commercial Canyon crops

	Start stem extension	Flowering	Mid grain-fill
Biomass (t/ha)	1.8	6.1	11.5

Stem Extension and Final Height

Key points
- As well as variety, height is affected by environmental and management factors
- Lodging control is an important aspect of the management of conventional oats

Height of Oats

Oat stems are typically made up of six internodes, with the internode below the peduncle at the top of the plant being the longest and those at the bottom of the stem the shortest. Stem extension starts at GS30 and the internodes continue to grow until final crop height is achieved at GS75.

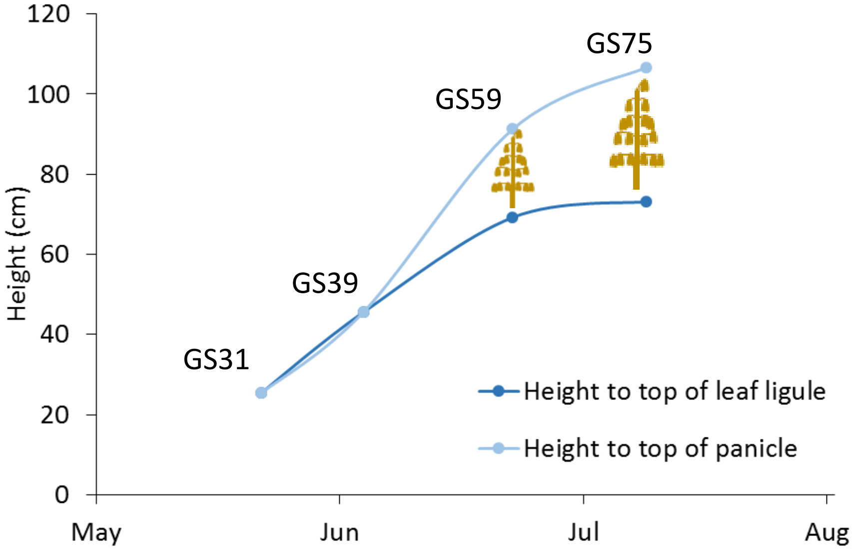
Panicle extrusion varies between varieties and variety types. Generally, the taller the oat cultivar, the better the panicle extrusion.

For consistency, the heights quoted in this guide are measured to the flag leaf ligule unless otherwise stated.

Lodging

Spring oats can be affected by lodging, although not as significantly as winter oats, and more modern varieties are generally less prone to lodging as they have stronger, slightly shorter stems.

The Canyon crops grown in these reference trials received a robust programme of plant growth regulators (PGRs). Oats can also be affected by brackling (buckling of the middle internodes). This doesn't usually affect yields or harvest, but can have a negative effect on grain quality.

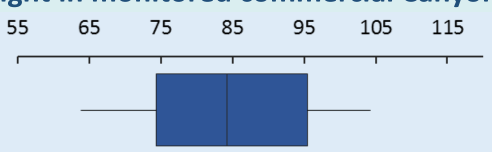


Final height (top of panicle)

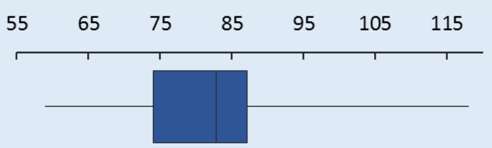
Mean = 108 cm
North = **110 cm**
South = **105 cm**

Median (with range) of final height in monitored commercial Canyon crops

Height (cm) to top of panicle pre harvest: North



Height (cm) to top of panicle pre harvest: South



Panicle Formation and Grain Filling

Key points

- Grain filling capacity is determined by the number of grains per panicle and grain size
- Potential grain number per panicle is determined before flag leaf emergence during spikelet initiation
- Grain filling determines final grain size but grain number has a greater effect on final yield

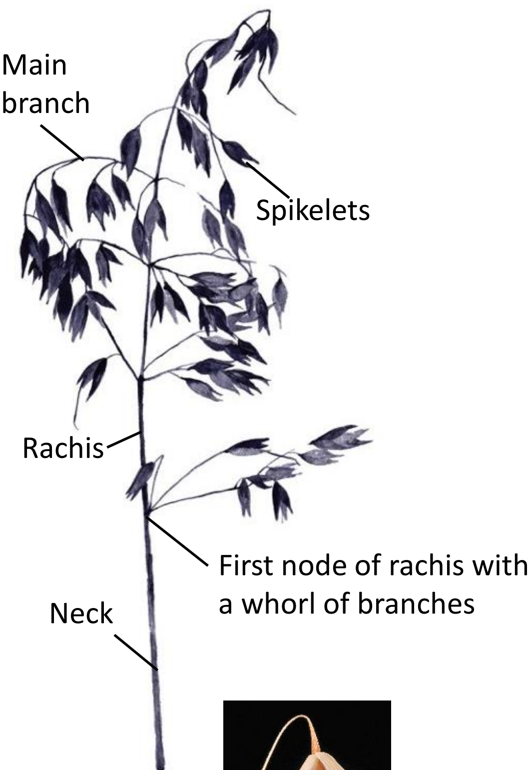
Grain Number Determination

Oat grains develop in a panicle. Each panicle has a number of branches (often ~4) radiating in whorls from 5-7 nodes on the central rachis.

Oat spikelets are found at the end of a small branches (pedicels) connected to the main branch. The spikelets contain 2 or 3 florets, each of which can produce a grain. The majority contain two grains which differ in size, giving a bimodal distribution of grain size. The number of spikelets on each whorl decreases towards the top of the panicle.

In oats the lemma and palea, which contain the grain, remain attached to the grain when harvested as the husk. Grain yields, and harvest indices include this husk.

Grains per panicle and panicles per m^2 are influenced by management practices. In oats, yield is more strongly related to grain number than grain size.



Oat spikelet containing 2 florets

Grains per panicle Mean = **42**
North = **36**
South = **45**

Panicle Weight

Panicle weight at harvest Mean = **2.2 g**
North = **2.3 g**
South = **2.2 g**

Grain Filling and Ripening

Photosynthesis and redistribution of stem reserves are both important for grain filling. Final grain dry weight, appearance and specific weight are all determined during grain filling. Grain ripening takes a further ~2 weeks before the grain is at an appropriate moisture content to harvest (ideally not greater than 15% moisture content).

Final grain weight (TGW 15% mc) Mean = **43.0 g** North = **47.0 g** South = **38.5 g**

Yield

Key points

- Grain yield is about half of the total biomass of the crop
- Panicle number per m^2 and grains per panicle determines final yield more than grain weight and size

Grain Yield

Grain yield is made up of three components, of which grain weight is the most stable. Most differences in yield between sites and seasons reflect differences in grain number rather than grain weight.

Grain yield (**15% mc**)**:** a product of **Panicles/m^2** and **Grains/panicle** and **Average grain weight**

Grain yield (15% mc)	Panicles/m^2	Grains/panicle	Average grain weight
7.0 t/ha	**370**	**42**	**43 mg/grain**

Harvest Index

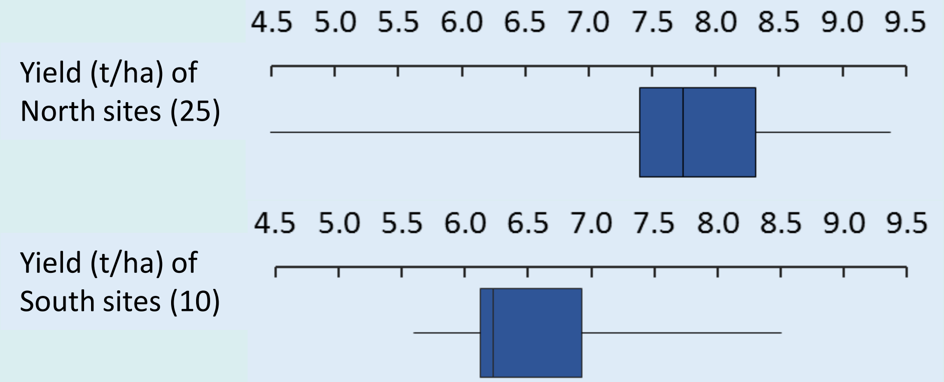
Harvest Index is the ratio of grain to total above ground biomass. Harvest index varies relatively little between sites and seasons, but does vary between variety types. These values are based on 100% dry matter.

Total biomass at harvest = 12.6 t/ha
of which grain = 48 %
straw and chaff = 52 %

Grain Moisture

Moisture is the most important consideration in storage of food grade oats and is primarily determined by environmental factors. Grain should be dried to between 11% and 15% moisture before storage. Improper moisture control can result in the growth of micro-organisms and loss of nutritional quality and the growth of micro-organisms that can cause spoilage.

Median(with range) of grower-reported yield in monitored commercial Canyon crops



Grain Quality

Key points

- As well as variety, crop nutrition strategies can impact grain quality traits in oats
- A lodged crop is associated with reduced grain quality

Specific Weight and Screenings

Grain specific weight is an indication of individual grain density. It is predominantly determined by plant variety genetics, and factors affecting the length of the grain filling period. Poorly managed crop nutrition and lodging can reduce specific weight. Milling oats should have a minimum specific weight of 50 kg/hl, with a target of approximately 55 kg/hl.

Oat screenings consist of small and broken grains and are removed during the cleaning stage before oats are processed. If the screenings level is too high, it can reduce milling throughput, and so it is important to reduce screenings on farm.

Specific weight Mean = **54.1 kg/hl**
North = **55.7 kg/hl**
South = **53.2 kg/hl**

Screenings Mean = **1.6 %**
North = **0.7 %**
South = **2.3 %**

Kernel Content, Grain Protein and Beta-Glucan

Kernel content is proportion of harvested oats (husk + groat) that is made up of the kernels or groats. It is a highly heritable trait but is also influenced by management practices, particularly increased N application.

In oats, protein content is significantly affected by the crop nutrition strategy, particularly the timings and rates of nitrogen applied. Environmental factors and variety also have an impact.

Beta-glucan, a form of soluble dietary fibre found in oats, has been shown to lower blood cholesterol. Beta-glucan content in oats is mainly determined by environmental factors and variety.

In the Opti-Oat project, protein and beta-glucan content were measured on groats on a dry matter basis.

Grain protein Mean = **14.8 %**
North = **13.1 %**
South = **16.0 %**

Beta-glucan Mean = **4.3 %**
North = **4.1 %**
South = **4.5 %**

Kernel content Mean = **70.7 %**
North = **72.9 %**
South = **69.0 %**

Median (with range) for grain quality traits in monitored commercial Canyon crops

	North	South
Specific weight (kg/hl)	54.5 (53.2 – 55.9)	52.0 (50.7 – 54.9)
Screenings (%)	0.5 (0.1 – 1.2)	0.5 (0.2 – 3.2)
Grain protein (%)	12.2 (11.2 – 13.4)	15.0 (13.8 – 16.2)
Beta-glucan (%)	3.9 (3.7 – 4.2)	4.6 (4.3 – 4.9)
Kernel content (%)	72.5 (70.2 – 76.2)	70.5 (68.4 – 76.3)

Glossary

Anthesis: Also known as flowering. This signifies pollination and the start of grain growth.
Assimilate: The product of the crop's synthetic processes, mainly photosynthesis. Measured as dry matter.
Average: Also known as **t**he mean. The sum of all the values divided by the number of values.
Benchmark: A defined measure of crop progress consistent with good final performance.
Beta-Glucan: A naturally occurring form of soluble dietary fibre found in the endosperm cell walls of oats and other cereal grains. Expressed as a percentage (%) of the groat.
Brackling: Buckling of the middle internodes of the stem.
Canopy: The above-ground parts of plants which are capable of photosynthesizing.
Carbohydrates: Products synthesised entirely from carbon dioxide and water; mainly starch and cellulose which are not 'soluble' and are immobile in the plant, and sugars (e.g. fructan) which are mobile in the plant and are classed as 'soluble', i.e. they dissolve in water.
Coleoptile: The first leaf structure to emerge from the seed at germination. It protects the first true leaves during emergence of the seedling. It contains little chlorophyll but may give rise to tillers.
Dry matter: Crop constituents other than water which remain after tissue has been dried. Often, 'total dry matter' refers to just the above ground parts of the crop. Dry matter is measured by weighing crop material after drying in a forced-draught oven at 80ºC until it reaches constant weight (approx. 24 hours).
Floret: A primary sub-component of a spikelet. Each floret has the potential to bear a single grain; while they retain this potential they are termed fertile florets.
Frost heave: Lifting of the soil surface, caused by freezing and expansion of moisture in the topsoil, often leading to stretching and breaking of the roots or sub-crown internode.
GAI: Green Area Index. The ratio between the total area of all green tissues, one side only, and the area of ground which they occupy.
Groat: The inner kernel of the harvested grain, without hull or husk.
Harvest Index: The ratio between grain yield on a dry basis and the total above-ground crop dry weight at harvest.
Hull or Husk: The lemma and palea of the floret which remain attached to the grain at harvest. The hulls are removed from the kernel or groat at the start of the milling process.
Internode: The section of stem between two adjacent nodes.
Kernel content: The proportion of harvested oats (husk + groat) represented by the kernels or groats.
Leaf blade: The upper portion of a leaf, from the tip to the ligule (junction with the sheath).
Leaf sheath: The basal portion of a leaf from node to ligule which encloses the stem and sheaths of younger leaves.
Ligule: A small structure at the junction of leaf sheath and leaf blade.
Lodging: Permanent displacement of a stem or stems from a vertical posture. Lodging can be considered as an event occurring within one day, although lodged stems may initially lean rather than lie horizontally.
Main shoot: The primary axis of the plant, from which the primary tillers are borne.
Mean: Also known as **t**he average. The sum of all the values divided by the number of values.
Median: The middle value when all values are ranked from lowest to highest. The median may provide more robust summaries than means when values are skewed because they are not influenced by exceptional values.
N: Nitrogen.
Node: The point at which a leaf sheath is attached to a stem.
Panicle extrusion: The distance between the base of the panicle and the flag leaf ligule.
Partitioning: The division of dry matter between organs.
Peduncle: The topmost internode, between the flag leaf node and the base of the panicle (the neck).
PGR: Plant growth regulator.
Photosynthesis: Formation of carbohydrates from absorbed carbon dioxide and water, driven by energy from sunlight, in the green tissues of the plant.
Phyllochron: The interval in thermal time from emergence of one leaf tip on a shoot to emergence of the next. Phyllochron is the reciprocal of leaf emergence rate.
Pollination: Reception of pollen produced in the anthers (bearing the male genetic complement) by the stigma, leading to fertilisation of the ovum (bearing the female genetic complement). Fertilisation of oats normally occurs within one floret, rather than between florets.
Rachis: The portion of the stem within the panicle (above the neck), bearing the rachillas and spikelets.
Ripening: The changes that occur in the grain between completion of growth and maturity. These include drying, and development and loss of dormancy. Grain is considered 'ripe' when it is ready for harvest – at less than 20% moisture.
Screenings: A by-product of the process of cleaning oats which includes anything that passes through a 2mm slotted sieve.
Senescence: Loss of greenness in photosynthetic tissues, normally brought about by ageing, but also by nutrient withdrawal, disease or drought.
Shoots: All the axes of a plant with the potential to bear a panicle, including the main shoot and all tillers. Shoots retaining the potential to form grain are termed 'fertile shoots'.
Specific weight: The weight of grain (corrected for variation in moisture content) when packed into a standard container. It is expressed in kilograms per hectolitre (100 litres). It is also referred to as 'bulk density' or 'bushel weight'.
Spikelet: The primary sub-component of the panicle. Each spikelet is contained within two glumes and consists of several fertile florets. Around 20 spikelets are borne on alternate sides of the panicle stem or 'rachis', and there is one 'terminal spikelet'.
Thermal time: The sum of the mean daily temperatures (mean of maximum and minimum) in the time period related to a specific development process. The accumulation begins after a base temperature is reached, e.g. for leaf development the base temperature is 0ºC, below this development ceases. Thermal time is expressed in 'degree days' (ºC days).
Tiller: A side shoot borne from the main shoot.
Vernalisation: A change in the physiological state of a plant from vegetative to reproductive brought about by a period of cold – can be applied to seeds or (in the case of wheat) to the young plant.
Waterlogging: Filling of soil pores with water to the extent that there is insufficient oxygen for normal root function.

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Further information

Further information and contact details of authors and partners in the Opti-Oat project can be found on the relevant websites:

www.Pepsico.com	www.adas.uk
www.envsys.co.uk	www.hutton.ac.uk
www.aber.ac.uk	www.niab.com


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