Most vineyards trellised, very few without a fixed row or vine spacing (en foule) for promotional or historic reasons, far from practical today as tractors replaced horses and manual weed control largely unknown

Most vines are grown in rows and many trained onto wires so that they can be

- accessed by both labor and machinery
- treated against pests and diseases
- crop can be harvested cleanly and easily

Trellising/training depends on

- climates
- soil
- site
- wine type/quality
- mechanization
- economics
- appellation rules
- personal preference

Trellising/training required for reasons such as:

- Physical support for the vine so that machines (sprayers, harvesters) can work efficiently and without damaging the vine
- Provide the best environment (micro-climate) for the health of the vine and the crop
- Make access for hand operations possible
- Produce grapes of the right quality, quantity at the right cost
- Make sure the vineyard keeps cropping for several decades

Most basic trellising system: a single short stake to which the vine is tied
e.g. a simple Gobelet system in plenty of vineyards (Grenache vines in Eden Valley, Gamay in Beaujolais, Garnacha in Spain, etc.)
Advantages: simple and cheap, does NOT limit quantity/quality of wine produced
Disadvantages:

- vine's annual canes and fruit will be near/on the ground
- crop protection more difficult
- slower harvesting
- limit the degree to which vineyard operations can be mechanized

Most extensive/expensive training/trellising system:
eg. the overhead pergola system, aka Parral and Tendone, Geneva Double Curtain (GDC) and Lyre systems, Scott Henry spur-pruned vines where rows at 2.5m and 1.3m between vines; high-wire Sylvoz with both spurs and hanging canes in NZ
require strong end-supports and anchors, an intermediate post every 4-6m and up to 10 wires per row. Perhaps cross bars, T bars, Y bars, and supports and assemblies of all shapes/sizes

Costs range from a few hundred $$ to over $40k

Pruning - Overview
Except minimal pruning, vines are pruned annually (winter pruning)
Goals:

- remove old fruiting wood
- replace it with freshly grown wood for the coming season
- allows growers to assess each vine individually to leave the correct amount of fruiting wood for expected yield to achieve *vine balance* (sg in theory, elusive and tricky in practice) as it grows canes and fruit
    - a vine carrying too little fruiting wood will likely grow too vigorously, shading both crop and canopy
    - a vine carrying too much fruiting wood will be less likely to ripen that crop might not provide

enough reserves for long term health

Vine's fruiting ability very variable and cropping level notoriously difficult to predict. [AI for crop prediction!!!!]

- as much as 50% variance in yields across vintages
- in cooler regions where weather conditions fickle and summer rain unpredictable despite same amount of fruiting wood left after pruning
- in warmer regions without irrigation, water stress/drought could reduce crop severely
- spring frost detrimental to crop level

Vines very sensitive to climate
Yield affected by weather conditions in both the harvest year and the year before when fruiting buds were forming:

- warm dry weather in previous year with good wood ripening in previous weather in autumn: buds well charged with flower potential for the coming year
- Early harvest (from early spring and warm summer) will allow vine to build up good leaves of reserves (starches/sugars) in its woody parts to improve chances of a good start next year
- in the cropping year, a warm spring will start the annual cycle early and by flowering the vine will be in best condition to pollinate flowers
- these positive condition produce maximum crop
- the opposite conditions: poor weather during previous year, then a hard winter leaves a vine with much less cropping potential for the coming season; a cold, late spring and poor flowering conditions: coulure or millerandage, reduced yields

The growers having pruned based on yield prediction at the time, are usually caught off guard by weather conditions

- If pruned for a heavy crop, crop thinning can help reduce a potentially heavy yield
- If pruned for a light crop, little can be done to compensate

Canopy Management: manage the vine from winter pruning, through flowering and fruit set and throughout the summer until harvest.
Seminal work 1991 Sunshine Into Wine by Richard Smart and Mike Robinson

- Acknowleged by UC's Centennial Symposium in 1980 as a starting point of their researches and the book being a summary
- Much of Smart & Robinson's work still controversial esp in traditional regions where low-vigor balanced vineyards are a fact of everyday life and Smart's zeal to change traditional practices not universally admired
- Sunlight Into Wine is concerned with the *indirect relationship between sunlight and wine*, i.e., *the effect of exposure of grape clusters (bunches) and leaves on wine quality*
- attempts to answer the following question: does a vine need to be struggling or low-yielding to make high quality wine or is it necessary for the leaves and clusters to be well exposed to the sun?

Prior to 1980, Prof Nelson Shaulis (under whom Smart studied for his PhD) at Cornell's NYS Agricultural experimental station in Geneva NY worked on canopy design for the production of Concord grapes, inventing GDC training system in the process, and is the founding father of canopy management.

Dr Alain Carbonneau (Bordeaux U, Montpelier U) devised Lyre training system was also a major influence on modern canopy management practices.

Canopy management activities outlined in Sunlight Into Wine:

- Winter pruning: determine the number of buds left on the vine for future cropping
- Shoot thinning (de-suckering): alter number of shoots which grow into maturity
- Summer pruning: shorten the annual growth of canes
- Shoot devigoration: reduce shoot length and leaf area
- Leaf removal: open up canopy in grape zone
- Trellis system changes: increased canopy surface area and reduce canopy density

Four rules of CM:

1. Measurement of canopy quality (is enough light reaching grapes and canes?): canopy gaps, size and color of leaves, canopy density, fruit exposure, shoot length, lateral growth, growing tips; the vineyard can then be categorized as having low, medium or high vigor
2. Pruning the vine in relation to the weight of wood produced by the vine (a good indicator of vine vigor): Ravaz Index [weighing all the wood produced by ~10 average sized vines then relating it to the weight of grapes produced by the same number of vines, a ratio of yield of grapes to weight of wood produced] can be set for low/med/high-vigor vineyards and vines pruned accordingly. Rough guide: Ravaz Index normally 5-10; if at >12, vines are very low in vigor (not producing enough wood or over-cropped); if <3, vines produced too much wood and not enough fruit. In either over/under situations, vines would be pruned accordingly in an attempt to bring them back into balance
3. Trellis design: central to achieving a balanced vine. Simple in low vigor sites. In moderate/high vigor sites, multi-cane VSP, Scott Henry, Te Kauwhata Two Tier (TK2T), GDC, Lyre, Sylvoz may be needed.
4. Annual canopy management (during the growing season after winter pruning)
    - shoot removal prior to flowering
    - topping of the vines to increase yield and remove excess growth (summer pruning)
    - removal of bunches to reduce crop load (green harvesting or crop thinning)
    - leaf removal (to open up canopy and improve light penetration)

additional techniques to ensure vine balance in *high-vigor vineyards*:

- *Restriction of water supply* to reduce shoot growth (only achievable in dry regions where vines are irrigated)
- *Grow cover crops* in vineyard alleyways to reduce the amount of water and nutrients avaiable to the vines and reduce vigor
- *Increase vine density* to create greater competition for water and nutrients
- Root pruning to reduce root area so that water and nutrient uptake is reduced

Vine density
Crop from a hectare depends on vine density AND the number of fruiting buds spread over that hectare however buds are trained/trellised.

In theory, each bud has the same potential to fruit and each inflorescence within the winter bud has the same potential to be pollinated and produce the same number of bunches of grapes, so for a given yield, a properly pruned vine bearing the correct number of buds for the space it occupies will provide the yield - the *charge* of buds is usually expressed in the number of retained buds per m^2 of space that the vine occupies.
In practice, its not entirely true. A vineyard with a low vine density might be bearing a larger crop than one with a high-density, depending on the climate, variety, rainfall/irrigation situation:

- vine's capacity for production in vigorous soils and in warm conditions (low density is common) and where vines are well supplied with water and nutrients is *higher*
- In cooler conditions with leaner less well fed soils esp in dry regions where irrigation is not allowed (*high density planting* more common), a vine's capacity for production is *lower*.

Climate - the most important factor in a grower's decision on vine density. In general:

- High-density planting preferred in cooler climates
    - vines will be under less strain, thus have more reserves of starches and sugars per kg of crop, be able to put more into fruiting ability for the coming season, produce better pollen and fertilize flowers more easily
    - wine will ripen less per vine more easily (at same cropping level), more likely ripen and produce fruit in poor seasons
    - the root system of vine occupying ~2.6m^2 (2m wide rows X 1.3m between vines) will probably occupy all the space available to it in competition with neighbor which help keep its vigor under control
    - more leaf area is needed in cooler climates to ripen same amount of grapes than in warm/hot climates; canopy management easier with cane-pruned VSP (Guyot, Pendlebogen, Scott Henry, Smart-Dyson, etc.) used as the leaf wall will be narrower/thinner and the fruit nearer to the weaker sun and protective sprays more easily onto grapes
- Low-density planting preferred in warmer climates

    - less leaf area required to ripen
    - soil warms up fast, vines less likely to suffer from cold spell at budburst/flowering, less strain on vines allowing incoming starches/sugars put to use supporting a higher crop level per vine rather than replacing reserves in vine structure
    - stronger sunshine/heat lead to denser canopy and grapes nearer to the center of the row more shaded yet still enough light/heat
    - vines in warm/hot climates more likely irrigated, which enables vines to be more easily fed with water/nutrients despite root system not as big as the area it occupies (e.g. 10m^2=4mX2.5m)

Economic considerations is another major factor, barring appellation regulations: *econmic situation* and *how quickly a yield is required* from a newly planted vineyard:

- high vine density (common in cooler regions) will come into full cropping sooner than low density sites as there is much less permanent wood to grow and train before fruiting could happen; accordingly shall the capital investment and the amount of work required, likely higher for quicker-yielding high-density vineyard bc highe number of vines to buy and look after and more posts/wires to install
- eg 2mX1.3m VSP, 3846 vines/ha @2.6m^2 per vine might give 35% crop in year two, 75% crop in year three, 100% crop since year four whereas 4mX2.5m GDC, 1000 vines/ha @ 10m^2 per vine might not produce any crop for three years and a full crop not before year six; by year six, both high/low density vineyards will in theory be fully cropping at the same yield and long-term financial might well be the same overall but expensive vineyard land needs to be financed and a return may be required as soon as possible thus a high-density earlier yielding system might be preferred; psychological factors might be at play when asked to choose between cropping in 3 years vs 6 years
- degree of mechanization of the vineyard work:
    - wider rows allow for usage of standard tractors/machinery, cheaper than narrow tractors tailored for vineyards
    - the number of running meters of the vineyard is pro rata the row width, favoring low density wide-rowed vineyards
        - high-density vineyard (2m wide rows) has 5000 meters run of row per hectare
        - low-density vineyard (4m wide rows) has 2500 meters run of rph
        - so a tractor/driver/sprayer/mower will cover twice as much vineyard in the day in the low-density vineyard wide-rowed vineyard for the same expense of capital/labor/fuel
        - a grape harvester will be more efficient on wider rows bc it will cover more areas given any row distance and a bigger harvester can carry a bigger tonnage of grapes before it has to stop and empty
        - other operations like pruning and canopy management will be cheaper per hectare in low-density vineyards with less savings than above
        - sprayers with large tanks will show substantial cost savings with lower run of row length per hectare

Other considerations for vine density and training system might include:

- the requirements of the climate and/or site - terraces, steeply sloping sites
- requirement for shade, and the demands of a particular harveting machine
- sites with potential frost problems: vines trained off the ground to minimize damage
- those who need bird netting: VSP provides better support for the nets
- many NZ vineyards adopted the Lyre system - aka double VSP - for the reason that nets can rest on top the trelliswork and drape down to the ground

Row width
Row width leads to a variety of long lasting consequences
Often determined by machinery requirements: existing tractors suited to a 2m row width, or being able to drive down every row in the farm's truck (ute in NZ) - 2.8m row width, or picking contractor requires a 3.5m row width for the harvester
Row width determined by the largest piece of machinery required to fit down the row.
In cooler regions, vines are often cane-pruned VSP trained, narrow vineyard tractors can fit down rows ~1m.
Narrow vineyard versions of tractors are common in mainstream European growing regions but rare? in new world regions. Narrow tractors are usu ~0.8-1m wide allowing for row widths 1.5-1.75m.
Narrow standard-ish vineyard tractors are 1.25-1.5m wide with narrow axles and typres fitted to slim down, suitable for row width 2-2.5m (actual width depends on trellising/training).
Standard tractors' width 1.75-2.5m requiring wider row widths, lower planting densities. The actual width of a

tractor determined by the settings of wheels upon the axels and the type of types used and soil types (some soil types require wider tyres to spread load out over a greater surface).
Too narrow a row width for the tractor/machine will cause damage to the vines.

Upon determining the widest piece of machine, the actual row width depend on the training system:

- Cane or spur-pruned VSP system useds will have a canopy that extends either side of the center line of the row by 350mm, when added to a ~1.3m wide tractor, gives a practical row width of 2m (1.3+2*0.35)
- A pruning system eg high-trained spur-pruned single-wire system with downward hanging canopy that extends 700mm each side of the ceter row line gives a row width of 2.7m (1.3m + 2*.7m) though a wide tractor would likely be used

Intervine distance and vine densities
For any given row width, intervine distance sets the vine density.
Besides en foule where random planting could give ~25k vines/ha, the shortest intervine distance ~0.8m with a 0.8m row width, gives a vine density of 15,625 vines/ha.
Also determined by natural limits of the vine itself:

- for cane-pruned vines it is determined by the length of ripe cane that the vine grow and at pruning can be laid down on fruiting wires. Usual planting distance ~1.2-1.4m, with a row width eg 2m, gives density of 4167-3571 vines/ha, typical for VSP trained vines
- for spur-pruned vines on extensive systems eg Lyre, GDC, overhead pergola, etc. vines can spread as far apart in the row as 3m with row widths of ~4m, giving 833 vines/ha, 12 times fewer than a traditional Burgundy vineyard at 10k vines/ha
- main reason for such disparity of vine density
    - in general, if an individual vine is carrying a smaller crop it will ripen fruit more easily (the variation of fruit per individual vine ought not to have bearing upon fruit quality but in practice it often does esp in marginal climates where the weather in the final weeks of ripening can be unpredictable)
    - a vine's capacity to ripen a given level of fruit depends on many factors but quality of site (amount of light and heat) is the most important
        - in cooler regions, no guarantee of good weather in ripening weeks, high vine density is preferred
        - high density encourages root competition: roots dig deeper into drier soils further away from the surface, controls vigor as vines compete for water/nutrients
        - in hot regions, where light/heat more guaranteed and vines irrigated, entensive low-density planting preferred where vines capable to carry higher crop levels; esp dry-farmed, wide spacing preferred to allow the same equipment even though vines may be carrying a smaller crop
        - low density with wide rows preferred where land is cheaper, no need to make use of each square feet and wide tractors, large capacity sprayers, wide mowers, big harvesters are cheaper and grapes can be produced at lower cost; wide rows also make for a lower cost vineyard as the number of posts, end-assemblies, anchors, vines, vine stakes, and vine guards is lower, so is the amount of labor needed to look after vines
        - quality argument: a traditional old world view of less fruit produced, better quality fruit resulted - debatable. Wine quality has much more to do with overall levels of crop for any given site/season. In some warm/hot regions with irrigation, limiting the yield per vine will often produce the finest fruit where yields per hectare get less relevant.
        - wide rowed low-density vineyards cost less to establish and farm, in the right climate with irrigation, they tend to favored by growers trying to produce bulk wines. Thus even though wines produced from wide rowed vineyards are generally lower in quality than wines from narrow-rowed sites, it's not because rows are wide.

Trellis height - length of canes
depends (to a certain extent) upon the requirements of the vine itself.

- cooler climates: grapes need around 12-15 leaves per cane to ripen; on VSPs in cool regions, sensible to train vines at least some way off the ground st grapes are not splashed by earth when it rains as Phytophthora rot, caused by mud getting onto the skin of the grape is often found on fruit close to the

ground; a gap in-between also allows for air-drainage, healthier conditions, less Botrytis at harvest
- warmer regions: less leaves needed to ripen
- traditional view: fruit ripens more easily close to the ground as heat stored during the day in top soil will be released to the atmosphere once the sun goes down, not sure how scientific it is.
- reasons against near the ground in favor of at more human-convenient height better for most manual operations: pruning, side shooting, leaf work, canopy management, harvesting, etc. much easier if the lowest wire is higher rather than lower (but still on *vignes basses - low vines* - in traditional regions eg Burgundy, overall trellis heights of 1.2m with fruiting wires at 300mm are not uncommon, back-breaking harvest but allows compact space saving straddle tractors, very narrow rows with high vine densities)
- overall height of trellis should also consider widths of rows, general advice to have overall height of vines no more than 80-85% of the row width, if ratio exceeded, some shading of the lower portions of trellis work might result, how damaging depends on orientation, size of crop, height of fruiting wire off the ground, overall quality of site/climate (eg in warm well-sheltered sites at mid-range crop ~10 tonnes/ha ~70 hl/ha, little harm with equal trellis height and row width, in wider rowed vineyards, trellis could be even higher)
- vignes hautes - high vines - are rarer in France than other EU regions usu have an overall height of 1.8m with fruiting wire at 600mm and thus a row width of ~1.5-2m for VSP cane- or spur-pruned; slightly wider rows - ~2.5m wide - might have an overall height of 2m, a fruiting wire at 800mm and a leaf wall of 1.2m high
- on wider rows (2.5m+) vine height is less important as the leaf area is not provided in a single-plane leaf-wall but spread over several planes (eg Lyre, GDC) or allowing vines to sprawl and grow multiple shoots. Overall heights seldom over 2m - except overhead training systems eg Parral, Tendone, Pergola etc. which are much higher and no mahcine/person would be able to pick grapes tho picking with ladders not uncommon in Italy.

Height of fruiting wood - mostly covered above. Most machine harvesters require the fruit to be no lower than 400mm from the ground and will have a problem picking it if it is above 1.75m from the ground. If hand harvested, constraints are patience or back of pickers at the lower end and the length of the ladders given at the upper end.

Downward trained vines
Grapevines prefer upward growth. Upward growing shoots are more vigorous and the number of potential flowers created within buds on canes growing upwards is greater.

Types of pruning

1. Cane pruning
2. Spur pruning
3. Minimal pruning

Different trellising, training, and pruning systems

1. Ballerina
2. Basket
3. Blondin
4. Bush
5. Chablis
6. Cordon
7. Cordon de Royat
8. Dopplebogen
9. Espalier
10. Eventail
11. Flachbogen
12. Geneva Double Curtain
13. Gobelet
14. Guyot
15. Guyot Double
16. Guyot Simple
17. Halb-bogen
18. Head trained

19. Kniffin
20. Lenz-Moser
21. Lyre
22. Minimal
23. Pergola
24. Parral
25. Pendlebogen
26. Single-pole
27. Scott-Henry
28. Smart-Dyson
29. Sylvoz
30. Tendone
31. Te Kauwhata
32. VSP

Materials used in trellising, training, and pruning