# FORAGES PRODUCTION

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## 1. DEFINITION OF FORAGE AND GOALS OF FORAGES PRODUCTION

Forage is defined as "edible parts of plants, other than separated grain, that provide feed for animals, or can be harvested for feeding" (Barnes and Nelson, 2003). Various forages can be produced on permanent grasslands (i.e. on meadows and pastures) and (cropped) arable land. Forage crops are crops grown to be utilized either by grazing animals or conserved as hay, haylage or silage before their utilization in feeding animals. Main livestock (and game) groups that consume forages are ruminants (cattle, sheep, goats and deer), pseudo ruminants (camels, llamas, and alpacas), and caudal fermenters (horses, donkeys, conies, rabbits). All aforementioned animals are principal herbivores that can efficiently digest cellulose and extract energy from it. Since cellulose is among the most ubiquitous compounds found in plant tissues, this gives them an advantage for survival in environments where the human can hardly find easily digestible foods like fruits, vegetables and cereals, namely grasslands and forests. Thanks to their ability to convert herbage into meat and milk they have enabled the spread of humanity into less favorable zones, far from civilized zones, and far from fertile and cultivated soils, even to semideserts.

Since forages are mainly produced by livestock farmers, with the purpose to feed their livestock, there stem out the main goals in forages production: to supply the present animals with the required quantity and quality of forage.

Therefore it is crucially important for forage producers to be familiar, at least with the basics of their herds' (or flocks') needs regarding the forage quantity and quality.

## 2. BASICS OF FORAGE QUALITY

Forages in various forms substantially differ in moisture (water content), and consequently in the related dry matter content (Table 1).

Table 1. Average moisture and dry matter content in various forms of forages

| Form of forage | Moisture (water content) (%) | Dry matter content (%) |
|---|---|---|
| Pasture, vegetative (fresh green forage) | about 81 | about 19 |
| Hay (cured or dried forage) | about 15 | about 85 |
| Silage (moist, fermented, acidic forage) | about 65 | about 35 |
| Haylage (semidry, fermented, slightly acidic forage) | about 55 | about 45 |

All nutrients are comprised in the dry matter (DM), so DM content comes as the first parameter of quality. Comprised nutrients may be classified in various ways but the most important is their allocation into the next few groups of chemical compounds: proteins, sugars, starch, fiber, fats and minerals. The basic chemical analysis provides us with data about contents of crude protein (CP, measured indirectly by Kjeldahl procedure, i.e. total nitrogen × 6,25), crude fat (EE, ether extract), crude fiber (CF, as a cellulose content) and crude ash (CA, as a rest after burning all organic compounds). Nitrogen-free extract (NFE, the rest) is being calculated mathematically and comprises mainly starch and sugars:

NFE (%) = 100 (%) – CP (%) – CF (%) – EE (%) – CA (%).

Digestibility or utilization rate of ingested nutrients by livestock is never complete, but high-quality forages have a digestibility of their organic matter usually between 75 and 90 % (such are grasses from vegetative phases till the emergence of inflorescence, lucerne and red clover from vegetative phases till the appearance of flower buds; mentioned data is valid for ruminants and had been taken from DLG, 1997). Low-quality forages have poor digestibility of their organic matter. For example, wheat straw has just about 50 % digestibility of its organic matter (DLG, 1997).

Digestibility of organic matter, or even of each group of nutritive compounds (proteins, fiber, fat, NFE) can be measured *in-vivo* or *in-vitro*. Data about crude nutrients content and their digestibility are already published for many types of forage in various tables. DLG and NRC tables are probably among the best ones. By multiplying the crude nutrient content with its digestibility, we get the product called "digestible nutrient content" and add the prefix "d" (dP, dEE, dF, dNFE).

Energy density expressed as Total Digestible Nutrients (TDN) is very often used because of its universality for ruminants. It is calculated by the following expression:

TDN (%) = dP (%) + dF (%) + dNFE (%) + dEE (%) × 2.25.

In TDN calculation the percentual content of digestible ether extract is being multiplied by 2.25 because fat releases 2.25 times more heat than other groups of nutrients (fiber, NFE) when burned.

The energetic value of various forages for lactating animals is very often expressed in net energy for lactation ($NE_L$, in $MJ/kg_{DM}$), but the calculation is more sophisticated and therefore not taught here.

Since forages comprise the whole above-ground plant parts, it is crucial for forage producers to distinguish the differences between plant parts regarding their quality, and to know how the succession of plant developmental phases (i.e. senescence) affects the forage quality. Above-ground plant parts include stems, leaves, may contain inflorescences, and even fruits (seeds). Stems do connect above-ground parts with roots. Stems are usually harder than leaves because they have to bear all above-ground parts. Therefore they comprise a lot of cellulose (fiber), which becomes increasingly lignified (hardened) with a succession of developmental phases (i.e. with senescence). Stems include main xylem and phloem veins for transport of water and minerals (upwards) and sugars and other organic compounds (downwards). Fibers in stems are generally less digestible than fibers found in leaves. However, stems of grasses may have appreciable energetic value due to the present sugars (e.g. in ryegrasses). Leaves are foliar organs aimed for photosynthesis, gasses exchange ($CO_2$ – $O_2$) and transpiration (water loss through evaporation). They are richer in plant protein than stems, they have tender fibers (non- or poorly-lignified cellulose), and are easier to chew and digest than stems. Therefore they are often more appreciated in animal nutrition than stems. Emerging inflorescences are still tender and well digested, but with succession to flowering or even to seed ripening they become harder and poorly digested. Ripen seeds of cereals and pulses are usually rich in starch or protein, or even in oil (depending on the plant species) and therefore they are considered to be concentrated feeds, or shortly, concentrates. Young plant tissues of leaves and stems (when the plant passes through vegetative phases) are usually tender, rich in protein and easily digested (i.e. rich in energy). With succession to visible reproductive organs (emergence of inflorescence in grasses, or budding in lucerne and clovers), above-ground herbage mass is being significantly increased by plant growth, but protein content and digestibility (i.e. energy density) slightly decreases. After full bloom there comes a rapid drop in plant protein concentration and digestibility of plant tissues as well. Poorly digestible plant material can't provide much energy for the livestock.

High-quality forages are easily digested, rich in energy and protein content, and are usually characterized by high voluntary intake by livestock when fed *ad-libidum*. Their tissues are soft, tender, often sweet, and their fibers are poorly lignified. Oppositely, forages of low quality are hard, heavy to digest, poor in energy and protein, and are usually characterized by low voluntary intake by livestock. Their tissues are hard because fibers have become lignified. High-quality forages allow for appreciable animal productivity (good liveweight daily gain, good daily milk yield) whilst low-quality forages can afford only poor animal performance (poor or negative liveweight gain, poor or no milk yield) unless they are amended with concentrates (cereal grains, pulses and/or oilseed cakes). Generally speaking, the herbage of legumes is richer in protein content but poorer in energy when compared to grasses in analogous developmental phases.

Assignment 1. Calculate TDN values for forages and grains listed in the table below.

| Forage or grain | DM (%) | Content in the DM (%) | | | | Digestibility (%) | | | | TDN (% in DM) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CP | EE | CF | NFE | CP | EE | CF | NFE | |
| Perennial ryegrass – vegetative, pasture | 16 | 24 | 4 | 18 | 42 | 83 | 59 | 87 | 84 | 76 |
| Meadow, summer growth | 22 | 14 | 4 | 28 | 44 | 64 | 55 | 72 | 70 | 65 |
| Lucerne hay, cut in budding | 85 | 19 | 2 | 28 | 41 | 74 | 41 | 47 | 72 | 59 |
| Meadow hay, tall grasses, tasseling | 85 | 11 | 2 | 29 | 50 | 59 | 47 | 65 | 68 | 62 |
| Whole crop maize silage | 35 | 8 | 3 | 20 | 64 | 56 | 79 | 63 | 78 | 72 |
| Wheat straw | 86 | 5 | 2 | 34 | 45 | 37 | 38 | 52 | 54 | 46 |
| Maize grain | 87 | 11 | 5 | 3 | 81 | 66 | 83 | 46 | 90 | 91 |
| Oat grain | 87 | 12 | 5 | 12 | 68 | 74 | 88 | 29 | 80 | 77 |
| Pea grain | 87 | 25 | 2 | 7 | 63 | 82 | 62 | 78 | 95 | 89 |

Assignment 2. Describe the above listed forages and grains either as rich or poor in energy and protein and fiber content.

Two fiber fractions are contemporary being very often used to appraise the forage quality: fibers extracted with neutral detergent (NDF) and ones extracted with acid detergent (ADF). NDF comprises hemicellulose, cellulose, and lignin, whilst ADF comprises only cellulose and lignin. Therefore the NDF is related to the content of all fibers whilst ADF only to heavy digestible ones. Three parameters describing the forage quality can be mathematically estimated from NDF and ADF content (Jeranyama and Garcia, 2004) and are very often used for hay pricing at the American lucerne hay market: digestible dry matter (DDM), dry matter intake (DMI) and relative feed value (RFV):

1) DDM (%) = 88.9 – [0.779 × ADF (%)]
2) DMI (% of BW) = 120 / NDF (%) …….. (BW denotes the bodyweight of live animal)
3) RFV = (DDM × DMI) / 1.29

The expression for DDM assigns a greater digestibility for lower ADF content, the expression for DMI assigns greater voluntary consumption for lower NDF content, and expression for RFV appraises the forages with highly estimated digestibility and intake.

Assignment 3. Estimate the DDM, DMI and RFV for forages listed below by using Jeranyama and Garcia (2004.) equations:

| Forage | % in DM of forage | | | % of DM | % of BW | RFV |
|---|---|---|---|---|---|---|
| | CP | NDF | ADF | DDM | DMI | |
| Lucerne, budding | 20 | 40 | 30 | | | |
| Lucerne, beginning of bloom | 18 | 43 | 33 | | | |
| Lucerne, fool bloom | 16 | 53 | 41 | | | |
| Lucerne, off bloom, pods formation | 14 | 56 | 43 | | | |
| Smooth bromegrass, booting | 10 | 63 | 35 | | | |
| Smooth bromegrass, end of flowering | 7 | 81 | 49 | | | |
| Whole crop maize silage | 10 | 48 | 28 | | | |
| Whole crop sorghum silage | 8 | 52 | 32 | | | |

At first sight the equations of Jeranyama and Garcia (2004.) appear very useful and universal, but a forage producer (or forage user) has to know that they undervalue grasses to lucerne and clovers. Namely, grasses generally contain more fibers than lucerne and clovers, so the equations will assign them the lower values for digestibility, intake and RFV. Conversely, fibers in grasses are easier to digest than fibers in lucerne

and clovers, which offsets the mentioned greater fiber content in grasses. Therefore the equations cannot justly compare legumes with grasses, but only legumes with legumes, and grasses with grasses (Ward and de Ondarza, 2008.). Equations are useless too for comparisons of maize whole-crop silage with clovers and grasses because they do not consider huge starch neither NFE content in maize silage.
Despite the numerous chemical analytic methods for forages evaluation, animals' productivity is still the best indicator of the feeding value of forages. Chemical analytic indicators are being used so often because they can be obtained quickly, whilst feeding trials with live animals may last for a week, month or months. And, some indicators are so obvious that the chemical analysis neither feeding trials aren't needed: young, green, leafy and tender herbage, often associated with the sweet taste of grass stalks, are the indicators for high quality forage, whilst old, stalky and hard herbage indicates the poor-quality herbage.

## 3. BASICS OF LIVESTOCK NUTRITIONAL NEEDS

Even when simplified, livestock nutritional needs have to be considered in at least two aspects: quantity and quality of feed that each animal should consume daily for the targeted animal performance (maintenance and productivity). Since the content of water in various feeds varies substantially (Table 1), and since all the nutrients (carbohydrates, proteins, fiber, fat, minerals) are comprised only in the dry matter of any feed, the livestock's quantity needs are usually being expressed in a dry matter (DM) per head per day ($kg_{DM}$/head/day).
Despite the expression of quantity needs in dry matter, we do not neglect the importance of water for animals' life, health, welfare and productivity.
Animals' daily needs will vary with species, age, reproductive phase, targeted productivity (daily milk yield or liveweight gain), stage of growth, and even with the breed.

### 3.1. Dairy cattle (milking cows)

For milking cows Beth Wheeler (1996) has given the targeted daily consumption (intake) of feeds, depending on daily milk yield (Table 2) and recommended quality of daily allowance (protein content, energy density in TDN units, fiber content), when served as a total mixed ratio (TMR) (Table 3).

Table 2. Targeted daily dry matter intake (DMI) for milking cows from mid to end of lactation (Beth Wheeler, 1996.)

| Daily milk yield ($kg_{milk}$/cow/day) | Cow's body weight (kg) | | | | | |
|---|---|---|---|---|---|---|
| | 450 | | 550 | | 650 | |
| | Daily dry matter intake (DMI), kg/head or % of body weight | | | | | |
| | % BM | kg/head | % BM | kg/head | % BM | kg/head |
| 10 | 2,6 | 11,7 | 2,3 | 12,7 | 2,1 | 13,7 |
| 20 | 3,4 | 15,3 | 3,0 | 16,5 | 2,8 | 18,2 |
| 30 | 4,2 | 18,9 | 3,7 | 20,4 | 3,4 | 22,1 |
| 40 | 5,0 | 22,5 | 4,3 | 23,7 | 3,8 | 24,7 |
| 50 | 5,6 | 25,2 | 5,0 | 27,5 | 4,4 | 28,6 |

Table 3. Recommended quality of total mixed ratio (TMR) for milking cows, depending on daily milk yield (Beth Wheeler, 1996.)

| Daily milk yield ($kg_{milk}$/cow/day) | Nutrient or energy content in daily consumed dry matter, DM based | | | | | |
|---|---|---|---|---|---|---|
| | Crude protein | $NE_L$ | TDN | Crude fiber | ADF | NDF |
| | % | MJ/kg | % | % | % | % |
| 0 (dry cow) | 12 | 5,23 | 56 | 22 | 27 | 35 |
| 20 | 15 | 6,36 | 67 | 17 | 21 | 28 |
| 30 | 16 | 6,78 | 71 | 17 | 21 | 28 |
| 40 | 17 | 7,20 | 75 | 15 | 19 | 25 |
| 50 | 18 | 7,20 | 75 | 15 | 19 | 25 |
| First 3 weeks of lactation | 19 | 7,00 | 73 | 17 | 21 | 28 |

There is notable that more productive cows consume more DM and need a richer ratio than less productive ones. In practical farming the DMI can often be lower than presented above, mainly due to a lower quality of forages being fed, due to lower share of concentrates in the TMR, and even due to suboptimal or excessive moisture content in the consumed allowance (optimum is between 50 and 75 % of DM in TMR; Wheeler, 1996). For example, Kolver and Muller (1998) have observed lesser DMI and milk yield for cows grazing high-quality pasture than for cows fed high-quality TMR (Table 4) in Pennsylvania (USA).

Table 4. DMI and milk yield for cows grazing high-quality pasture and cows fed high-quality TMR (Kolver and Muller, 1998.)

| Parameter | Grazed pasture | TMR |
|---|---|---|
| DMI (kg/head/day) | 19,0 | 23,4 |
| DMI (% of BW/day) | 3,39 | 3,93 |
| Milk yield (kg/head/day) | 29,6 | 44,1 |
| Allowance composition | perennial ryegrass, white clover | whole-crop maize silage, legumes silage, concentrates |
| DM content (%) | 17,0 | 58,2 |
| Crude protein content (CP % in DM) | 25,1 | 19,1 |
| NDF (% in DM) | 43,2 | 30,7 |
| ADF (% in DM) | 22,8 | 19,0 |
| $NE_L$ ($MJ/kg_{DM}$) | 6,9 | 6,8 |

Lower DMI on pasture was probably caused by greater fiber (NDF and ADF) and water content in pasture than in TMR, because of the required movement of grazing animals in search for the ungrazed pasture areas, and because of smaller feed particles in TMR that enable for the faster passage of feed through the digestive system. Rotational grazing management in their research was optimal: initial herbage mass was about 2.9 $t_{DM}$/ha and residual was about 1.5 $t_{DM}$/ha.

The expected effects of NDF and ADF content found in forages on DMI in cows were presented by Wheeler (1996) too (Table 5). The presented data reveal that forages with high fiber content diminish the DMI, and vice versa.

Table 5. Maximum DMI of hay for cows, depending on hay quality (Wheeler, 1996)

| | | | | DMI (% of BW and absolute value in kg) | | | |
|---|---|---|---|---|---|---|---|
| | Content (%) in DM of hay | | | | A cow's BW (kg/head) | | |
| Hay quality | Crude protein (CP) | ADF | NDF | (% of BW) | 400 | 500 | 600 |
| Excellent | >18 | <33 | <43 | 3,0 | 12,0 | 15,0 | 18,0 |
| Good | 16-18 | 33-37 | 43-48 | 2,5 | 10,0 | 12,5 | 15,0 |
| Fair | 13-15 | 38-41 | 49-53 | 2,0 | 8,0 | 10,0 | 12,0 |
| Poor | <13 | >40 | >53 | 1,5 | 6,0 | 7,5 | 9,0 |

### 3.2. Beef cows

Beef cows (cows that give birth and suck to calves raised for beef fattening) are expected to consume less than intensive milking cows. According to Hibbard and Thrift (1992.; cit. Lalman and Richards, 2014.), the expected DMI of forages for beef cows varies between 2.7 and 1.8 % of BW, depending on the cow's stage (suckling or dry) and forage quality (Table 6).

Table 6. Capacity for forages DMI in beef cows (Hibbard and Thrift, 1992; cit. Lalman and Richards, 2014)

| | Forages DMI capacity (% of BW) | |
|---|---|---|
| Type and quality of forages | Dry cow | Suckling cow |
| Low quality forages: hay of legumes and grasses cut in late developmental phases, straw of cereals (<52 % TDN in DM) | 1,8 | 2,2 |
| Mid quality forages: dry summer or autumn pasture, hay of legumes cut at the end of bloom, hay of grasses cut from booting till beginning of flowering (52 to 59 % TDN in DM) | 2,2 | 2,5 |
| High quality forages: lush growing pasture, hay of legumes cut till bloom, hay of grasses cut until the end of booting (>59 % TDN in DM) | 2,5 | 2,7 |
| Whole-crop silages | 2,5 | 2,7 |

According to NRC (1996; cit. Kerley and Lardy, 2007), beef cows for raising calves on pasture need daily DMI about 2.3 to 2.4 % of BW during suckling (first six months upon birth) and about 2.1 % of BW after weaning (the rest six months until the next birth). The energy density of the allowance during the first three months of suckling should be about 60 % TDN (in DM) with a gradual decrease to 45 % TDN (in DM) at weaning. Crude protein (CP) content should be at least 11 % (in DM) during the first three months of suckling with a gradual decrease to 7 % (in DM) at weaning.

### 3.3. Growing steers and heifers

After an initial BW of 200 kg/head, the targeted DMI for fattening steers and heifers can be about 2.5 % of BW (Table 7; Lalman and Richards, 2014). At the beginning of fattening the daily allowance should contain more crude protein (CP) and energy (TDN) than at the end of fattening. It is also valid for the greater targeted liveweight average daily gains (ADGs).

Table 7. Nutritional needs for fattening steers, heifers and calves (Lalman and Richards, 2014)

| Body weight (kg/head) | Targeted ADG (kg/day) | Daily DMI (kg/head/day) | Relative daily DMI* (% of BW/day) | TDN (% of DM) | CP (% of DM) |
|---|---|---|---|---|---|
| 135 | 0,90 | 3,87 | 2,87 | 69 | 16,2 |
| | 1,13 | 3,83 | 2,84 | 75 | 18,9 |
| | 1,35 | 3,69 | 2,73 | 83 | 22,2 |
| 180 | 0,90 | 4,82 | 2,68 | 69 | 14,1 |
| | 1,13 | 4,77 | 2,65 | 75 | 16,3 |
| | 1,35 | 4,59 | 2,55 | 83 | 19,0 |
| 225 | 0,90 | 5,72 | 2,54 | 69 | 12,8 |
| | 1,13 | 5,63 | 2.50 | 75 | 14,7 |
| | 1,35 | 5,45 | 2,42 | 83 | 16,9 |
| 270 | 0,90 | 6,57 | 2.43 | 69 | 11,9 |
| | 1,13 | 6,48 | 2,40 | 75 | 13,6 |
| | 1,35 | 6,21 | 2,30 | 83 | 15,7 |
| 315 | 0,90 | 7,34 | 2,33 | 69 | 11,4 |
| | 1,13 | 7,25 | 2,30 | 75 | 12,8 |
| | 1,35 | 6,98 | 2,22 | 83 | 14,6 |
| 351 | 0,90 | 9,41 | 2,68 | 60 | 9,2 |
| | 1,35 | 9,18 | 2,62 | 70 | 11,4 |
| 378 | 0,90 | 9,95 | 2,63 | 60 | 8,8 |
| | 1,35 | 9,72 | 2,57 | 70 | 10,8 |
| 405 | 0,90 | 10,49 | 2,59 | 60 | 8,4 |
| | 1,35 | 10,22 | 2,52 | 70 | 10,2 |
| 432 | 0,90 | 10,98 | 2,54 | 60 | 8,1 |
| | 1,35 | 10,76 | 2,49 | 70 | 9,7 |
| * calculated by authors as DMI / BW ratio | | | | | |

### 3.4. Sheep (and goats)

According to NRC (1985) tables, sheep's and lambs' DMI depends on the reproductive stage, age and mature body weight of sheep breed. Below are presented data for heavier sheep breeds, with an average mature BW of about 70 kg/head (Table 8). The highest relative DMI (relative to BW) and the highest quality of allowance are required to lactating ewes (giving suck to lambs) and growing lambs.

Table 8. Sheep (mature BW = 70 kg/head) and weaned lambs nutritional needs (NRC, 1985)

| | Daily DMI | | CP | TDN |
|---|---|---|---|---|
| | kg/head | Relative to BW (%) | (% of DM) | (% of DM |
| Sheep, dry | 1,2 | 1,7 | 9 | 55 |
| Sheep, gestation | 1,4 | 2,1 | 9 | 55 |
| Sheep – last third of gestation * | 1,8 | 2,7 | 11 | 62 |
| Sheep – lactating, giving suck (first 8 weeks) * | 2,6 | 3,8 | 14.5 | 65 |
| Lamb, BW = 20 kg** | 1,1 | 5,0 | 17 | 80 |
| Lamb, BW = 30 kg** | 1,3 | 4,5 | 15 | 77 |
| Lamb, BW = 40 kg** | 1,5 | 3,8 | 14 | 77 |
| Lamb, BW = 50 kg** | 1,6 | 3,2 | 13 | 77 |
| Ram, BW = 100 kg | 3,0 | 3,0 | | |
| * Average between sheep with single and twin lambs<br>** Average between moderate- and rapid-growth potential lambs | | | | |

The nutritional needs of goats may be considered similar to the sheep's, with the particular preference to browse.

### 3.4. Horses

According to Fouts (2008), daily DMI for horses is usually between 1.5 and 2.5 % of BW. The share of forages in the daily allowance has to be high, in line with the general rule for hay consumption of 2 % of horse's BW. This means that a horse of a BW = 500 kg/head needs 10 kg of hay per day. Grazing on pasture decreases the need for hay. Working loads (exercises for sport horses or pulling for draft horses) bring the need for supplementation with cereal grains to enhance the animal's energy intake. Growing foals and lactating mares (giving suck to foals) have greater nutritional needs and can daily consume up to 3 % of DM relative to their BW. Considering the quality of daily allowance, here we refer to Fouts (2008) values regarding the horses' daily needs for digestible energy (DE) and crude protein consumption (CP) (Table 9).

Table 9. Daily needs of heavy draft horses for digestible energy (DE) and crude protein (CP), depending on the age and activity of a horse (Fouts, 2008.). Energy and crude protein concentration are calculated by authors, based on the expected daily DMI.

| Class of a horse | DE (MJ/day) | Equivalent* TDN=6,5×DE (kg/day) | CP (kg/day) | TDN concentration in DM (% in DM) at DMI = 2 % of BW | CP concentration in DM (% of DM) at DMI = 2 % of BW |
|---|---|---|---|---|---|
| Mature horse, BW = 900 kg, light work | 176 | 1144 | 1,38 | 63 | 7,7 |
| Mature horse, BW = 900 kg, moderate working load | 201 | 1307 | 1,55 | 72 | 8,6 |
| Mature horse, BW = 900 kg, heavy working load | 259 | 1638 | 1,81 | 93 | 10,1 |
| Lactating mare, BW = 900 kg, 3rd month suckling | 219 | 1424 | 2,64 | 79 | 14,7 |
| Gestating mare, BW = 900 kg, 9th month of gestation | 145 | 943 | 1,43 | 52 | 7,9 |
| Yearling | 141 | 917 | 1,52 | 91 | 15,0 |
| Two-year old, in training | 187 | 1216 | 1,60 | 76 | 9,0 |

## 4. EXPRESSING YIELDS OF FORAGES

The yield of forages is usually being expressed per unit area (per hectare or acre). It may be expressed as a *natural yield* of the forage mass *as it is*, and/or as a pure *dry matter yield*.

Natural yield is calculated as follows:

$Y_N$ (kg/ha) = $PQ_N$ (kg) / HA (ha)

, where $Y_N$ denotes the yield, $PQ_N$ produced natural quantity and HA harvested area.

Dry matter yield ($Y_{DM}$) is calculated by multiplying the natural yield with its dry matter content:

$Y_{DM}$ ($kg_{DM}$/ha) = $Y_N$ (kg/ha) × $DM_{CONCENTRATION}$

In most cases the reported yield refers to an annual yield, which can be separated into yields of successive cuts taken during the same vegetation season, for example, the yield of the 1st cut, 2nd cut, etc.

Assignment 4. Calculate the pure DM yields of various forages if there were measured natural yields and DM contents shown in table below:

| Forage | Measured natural yield (t/ha) | Measured DM concentration (%) | Pure DM yield ($t_{DM}$/ha) |
|---|---|---|---|
| Whole-crop maize silage | 50 | 35 | |
| Lucerne hay | 10 | 85 | |
| Perennial pasture | 30 | 18 | |

## 5. SOIL AND CLIMATE IN FORAGES PRODUCTION

Soil quality and position largely determine the productivity of grown forage crops. Deep and fertile soils have great water- and nutrient-holding capacity thus enabling the high yields of forage crops. On deep and fertile soils there are mainly produced arable forage crops, like silage maize, lucerne and lucerne-grass mixes. Soil acidity and poor drainage limit the survival and yield of lucerne, so alternatives have to be chosen (red clover, white clover, birdsfoot trefoil, fescue grasses and cocksfoot grass), which are less yielding and more drought sensitive. Silage maize yields are significantly lower on such a soils too. Soils with pronounced problems (clayey, shallow, inclined, stony) are unsuitable for arable forage crops, and therefore they are usually used as permanent grasslands.

In continental and Mediterranean types of climates, the drought tolerance is much appreciated so the lucerne is probably the number one choice there. In humid and maritime climates, with plenty of rainfall during vegetation, perennial grasses are usually the first choice.

## 6. ANNUAL DM YIELD AND ANNUAL DM CONSUMPTION DETERMINE THE LAND'S CARRYING CAPACITY

Herd's (or flock's) annual needs for forages (or all feeds together) are a yearlong (year-round) sum of individual daily needs of each animal in a respective herd (or flock). Daily and cumulative annual DM consumption per head can be projected by using the expected daily DMI, which will be shown in the further text and graphs.

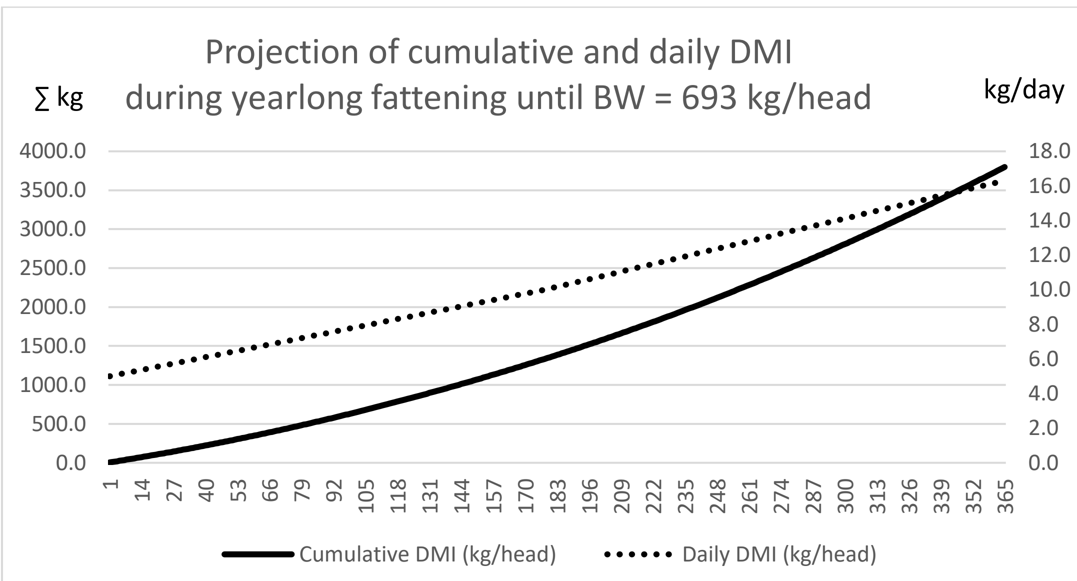
### 6.1. Projection for milking cows

With approximation that milking cow (with BW = 600 kg/head) has average daily DMI of 3.2 % of BW during 305 days of lactation and 2.2 % of BW during 60 days of dry period, an annual DM consumption can be estimated as follows:

DM consumption during lactation = 3.2 % × 600 kg/head × 305 days = 5856 kg/cow/year
DM consumption during dry period = 2.2 % × 600 kg/head × 60 days = 792 kg/cow/year
Annual DM consumption = 4209 kg/head/year + 792 kg/head/year = 6648 kg/cow/year

### 6.2. Projection for beef steers and heifers

With approximation that beef steers and heifers start fattening with initial BW = 200 kg/head, that the expected liveweight average daily gain (ADG) is 1.13 kg/head/day during the first 177 days and 1.35 kg/head/day during the last 188 days, and that the average daily DMI is 2.5 % of BW, there can be produced a simplified projection of daily and cumulative DMI during the yearlong fattening, until the final BW = 693 kg/head (Graph 1). Such a projection has estimated an annual DMI of about 3800 kg/head/year. When there are expected lower ADGs, for example 0.9 kg/head/day (first phase) and 1.13 kg/head/day (second phase), until the final BW = 571 kg/head, projection gives somewhat lesser annual cumulative DMI (about 3500 kg/head/year, graph not presented here).




Graph 1. Projection of cumulative and daily DMI for fattening steers/heifers with ADG 1.13 kg/head/day during the first 177 days and 1.35 kg/head/day during the last 188 days of fattening.

It is obvious that daily DMI per head is more than three times greater at the end of fattening than at the beginning and that during the second phase of fattening animals consume more DM than during the first phase (about 2500 vs. about 1300 kg of DM, respectively). However, the fattening may be for some reasons extended over a year ahead, thus increasing the required cumulant of DMI.

Daily and cumulative DMI for beef cattle grazed on pasture without supplementation can also be projected by using the expected daily DMI (about 2.5 % of BW) and assumed BW values (starting BW + daily increments). ADGs on pasture are likely to be between 0.5 and 1.2 kg/head/day, depending on the quality and abundance of pasture (abundant, lush and high-quality pasture enables for a greater ADGs), and on the age of cattle (older ones grow faster than younger ones, unless they come close to the maximum bodyweight).

### 6.3. Projection for sheep

Gravidity in sheep lasts for five months, lactation during the next five to six months, and dry period about next one to two months. Based on the expected daily DMI during gravidity of about 2.5 % of BW, during lactation of about 3.5 % of BW, and during the dry period of about 2 % of BW, there can be projected an annual DMI for sheep (below is presented example of sheep breed with about 70 kg/head mature BW):

DMI during gravidity: 150 days × 70 kg/head × 2.5 % DMI of BW = 150 days × 1.75 kg/head/day = 262,5 kg/head
DMI during lactation: 170 days × 70 kg/head × 3.5 % DMI of BW = 150 days × 2.45 kg/head/day = 416,5 kg/head
DMI during dry: 45 days × 70 kg/head × 2.0 % DMI of BW = 45 days × 1.4 kg/had/day = 63 kg/head
Annual DMI = 262.5 kg/head + 416.5 kg/head + 63.0 kg/head = 742 kg/head

The presented projection for sheep can overestimate the annual DMI in cases where sheep are not milked. Namely, the majority of lambs are being sold or slaughtered until they are four or three months of age. In the absence of suckling lambs, sheep, if not milked, have to be dried, and thereafter their daily DMI gradually approaches the level for the dry period. Also, smaller breeds consume less because of their smaller BW. On karst pastures, where the forage on offer is often very low and scarce, daily and annual DMIs are lesser than projected, as well as the performance of sheep and lambs (lesser sheep daily milk yields, poorer lambs' liveweight ADGs).

### 6.4. Projection for horses

Horses are expected to have a daily DMI of about 2 % of their BW, with exceptions for broodmares and growing foals which consume up to 3 % of BW. Heavy-working draft horses and horses in intensive training are expected too to consume more than 2 % of their BW. The simplest projection for idle horses is like this: 500 kg/head of BW × 2 % DMI × 365 days = 3650 kg/head/year. Idle horses can thrive solely on good forages, while working horses have to be supplemented with cereal grains.

### 6.5. Quick estimation of land's carrying capacity

Lands carrying capacity depends on the productivity of land (average DM yield per unit area, $kg_{DM}$/ha/year) and annual needs per head of livestock ($kg_{DM}$/head/year) or per livestock unit ($kg_{DM}$/LU/year) (Figure 1). Annual needs are comprised of annual DMI plus an adjustment for the expected losses (i.e. incomplete utilization).

The livestock unit used here presents the liveweight equivalent of 500 kg/head of herbivore livestock. Though, in American literature can often be found an animal unit (AU) that mainly refers to the liveweight equivalent of 1000 pounds/head (454 kg/head).

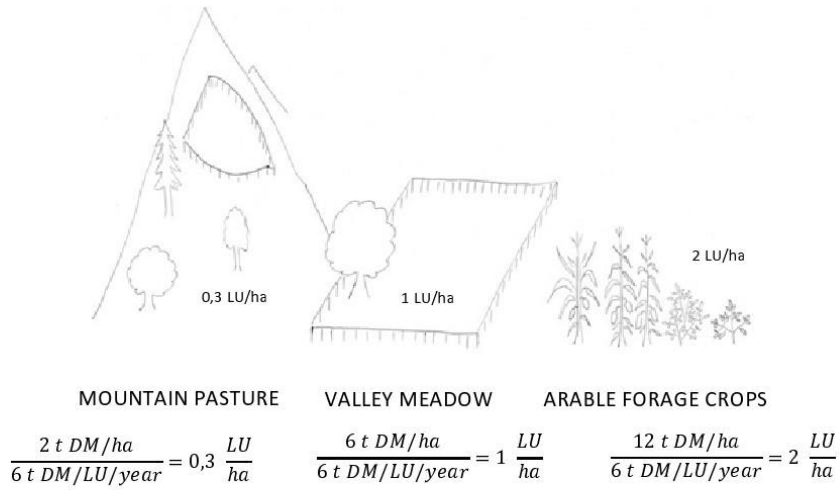



Figure 1. When there are expected constant annual DMIs (about 6 $t_{DM}$/LU/year), the land's carrying capacity depends on the expected annual DMI yield.

To estimate the carrying capacity of our land resources, we have to come to know about the:

- expected average DM yields of our forages (and of grains too if they are being used to feed our livestock)
- our livestock expected annual DMI of forages (and of grains too if they are being used to feed our livestock)
- average utilization efficiency for various forages being fed (pasture, hay, silage).

Estimation of carrying capacity then comes through a simple calculus:

CC (LU/ha) = [ $Y_{DM}$ ($kg_{DM}$/ha) / $DMI_{annual}$ ($kg_{DM}$/LU) ] × UE

, where CC labels the carrying capacity, $Y_{DM}$ labels the pondered (weighted average) DM yield, $DMI_{annua}$ labels the expected annual DMI per Livestock Unit, and UE labels the utilization efficiency (always between1 and 0).

Weighted average (or *ponder*) of DM yields of forages (and grains) should be used when there is more than one forage crop being used, in order to consider various planned shares of each forage (and grain) in an annual DM consumption.

For a quick estimation, a simplification of average daily DMI between 2.5 and 3.0 % of BW for herbivore livestock can give us an annual DMI between 4563 and 5475 $kg_{DM}$/LU/year. To offset the expected losses during grazing, harvesting and storage (probably between 5 and 25 % of the produced DMI), we should increase the annual needs for the produced DM, to the quantity roughly between 5500 $kg_{DM}$/LU/year (for daily DMI 2.5 % of BW) and 6500 $kg_{DM}$/LU/year (for daily DMI 3.0 % of BW), or even more simplified to about 6 $t_{DM}$/LU/year. Considering the fattening steers and heifers, either on pasture or TMR-fed, Graph 1 shows that annual consumption is likely to be below 4000 $kg_{DM}$/head during the first year of fattening.
When making quick estimations for farms placed in areas with forage scarcity (karst and alpine pastures for example), there should be assumed modest average daily DMI, likely about 2 % of BW, i.e. 10 $kg_{DM}$/LU/day. This gives a rough estimation of annual DMI at about 3,650 $kg_{DM}$/LU/year, and annual need

of about 4,500 $kg_{DM}$/LU/year when adjusted for the expected average utilization efficiency of, for example, 23 %.

Assignment 5. Estimate the carrying capacities of a valley meadow and alpine pasture if the expected annual DMI is 5500 $kg_{DM}$/LU/year, utilization efficiency 75 % (or 0.75), annual DM yield of a meadow is 6 $t_{DM}$/ha, and of pasture is 3 $t_{DM}$/ha. Assume that farms (on a meadow and pasture) feed forages only (to obtain the products marketed as a grass-fed).

It's worthy to aware the readers that it is not wise to load a farm with a stocking rate close to the carrying capacity of its land resources, because, in drought years, the yield of forages can drop to less than half of an average. Shortage of feeds in such a circumstance can lead to a decrease in livestock productivity (milk yield, body weight gain), and even to starvation. Option to purchase the missing feeds can be too expensive, while the sales of the present livestock can bring an insufficient income, making it hard to resume the production after the shortage is over. In some environments, excessive rainfall and flooding can cause a shortage as well.

## 7. ARABLE FORAGE CROPS

Arable forage crops include various cereals (warm and cool-season ones), annual and perennial legumes, some perennial grasses grown on arable land, and some roots and brassicas. From the historical point of view, the importance of arable forages is relatively new. Namely, the large herbivores have co-evoluted with plant communities of wide permanent grasslands, making the perennial grasses (with a small share of perennial legumes and forbs) their principal feed. In the beginnings of livestock husbandry, men were pastoralists. Forages grown on arable land (cereals' straw, pure red clover and pure lucerne) came into livestock nutrition probably sometime after livestock domestication. The broadest and most dramatic shift to almost solely arable forages in many farms occurred during the second half of the 20$^{th}$ century. This was driven by the introduction of silage maize into cattle nutrition.

### 7.1. Cereals

Cereals worldwide are predominantly cultivated to produce grains for human food. However, in many areas they are grown to produce whole-crop forages too, with the purpose to feed various herbivore livestock, but mainly cattle. In some cases, cereal grains are harvested for human consumption, while the rest of the plants (stalks, leaves, straw) are fed to livestock.

#### 7.1.1. Warm-season cereals

The most important warm-season cereals for forage production are maize (*Zea mays* L.), sorghum (*Sorghum sorghum* L.), proso millet (*Panicum miliaceum* L.), pearl millet (*Pennisetum glaucum* L.) and foxtail millet (*Setaria italica* L.). Sudangrass (*Sorghum sudanense* L.) is assigned here despite it is not a cereal crop, but forage only, for the reason of its great resemblance and relatedness to forage sorghum, with its agronomy very similar to sorghum too. All of the mentioned species belong to the grasses family (*Poaceae*, or older name *Gramineae*), and are grown as annual crops. They all originate from geographic zones with a warm climate, and therefore they can thrive in temperate zones during the warm season (frost-free) only. Maize and sorghum are recognized for their great yield, sudangrass for its good regrowth after cutting or grazing and millets for their very short vegetation period required to produce satisfactory yield.

7.1.1.1. Forage maize (corn)

The main forage produced by maize crop is whole-crop silage, harvested close to the end of maize vegetation (when the grain is at doughy to hard dough state). Besides, it is appreciated as fresh green herbage for cattle and horses (during the milk and doughy grain developmental stages of maize). Ensiled wet grain and corn-cob mixture are very often being conserved instead of storing the dry grain at the silo, but these silages are considered concentrates, not true forages.

Whole-crop maize silage is nowadays a main source of energy in dairy cattle ratios in Europe and North America (Ettle and Schwarz, 2003; Contreras-Govea et al., 2009). This is due to maize's high energetic value and superior forage yield when compared to other forages in favorable climates and soils. Although maize's great yielding capacity and high energetic value were known long before, the whole-crop maize forage has gained popularity yet after the adoption of ensiling technique, because it was impossible to conserve it for year-long consumption until inventions of silage harvesters that chop the maize herbage to a very short particles (about 1.5 cm in length).

Despite its great popularity in modern cattle nutrition, maize silage is poorly accepted in other herbivore species nutrition, mainly due to problems that can rise when feeding them with silages (i.e. anaerobically fermented acid forages).

For the clarity of further text, we present here the most important developmental phases of maize in forage production (some are shown in Figure 2):

1. seed germination
2. emergence
3. development of leaves, in succession
4. tasseling – tassel appearance (male inflorescence)
5. silking – silk appearance (recipients of pollen at the female inflorescence), usually is synchronized with tasselling
6. flowering and fertilization
7. kernel (grain) formation on ears
8. milky kernel (grain)
9. doughy kernel (grain)
10. full ripeness, kernel (grain) is hard.

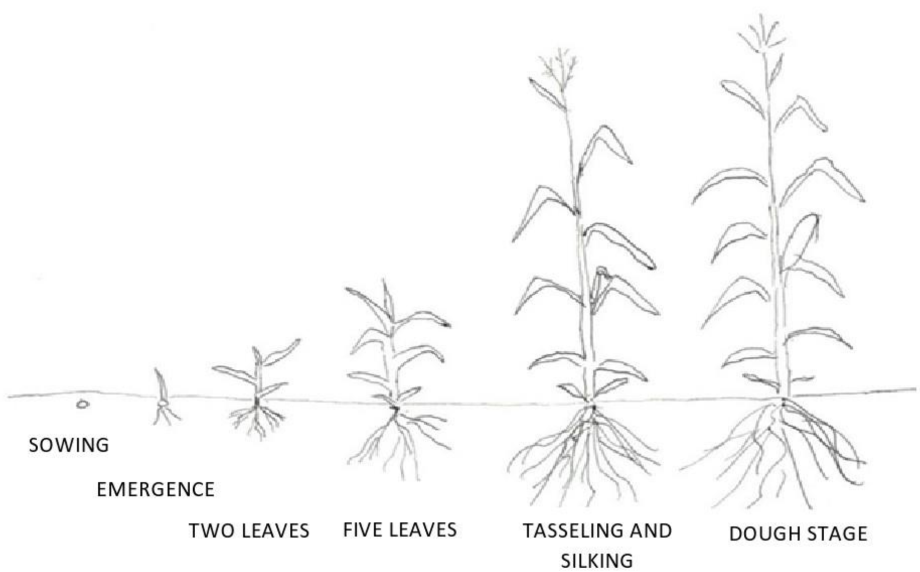



Figure 2. Some developmental phases of maize

7.1.1.1.1. Feeding value of maize forage

DM content in the whole-crop maize herbage rises during the succession of developmental phases. TDN value of the whole-crop maize at harvest is usually between 71 and 73 % (in DM) from milky to hard dough grain stage (Table 10). Although rich in energy, maize forage is poor in crude protein content (just between 8 and 9 % in DM). If the share of ears is found lesser than in Table 10, the expected TDN values would be somewhat lower.

Table 10. Feeding value of the whole-crop maize forage, dry grain and corn cob mixture (DLG, 1997)

| Animal feed | Maize developmental stage | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Fresh whole-crop herbage | Earing | 17 | 10,4 | 25,8 | 6,04 | 68,7 |
| | Milky grain stage (share of ears about 30% in herbage DM) | 21 | 9,0 | 22,3 | 6,47 | 72,9 |
| | Early dough stage (share of ears about 40% in herbage DM) | 27 | 8,6 | 20,5 | 6,39 | 72,0 |
| | Hard dough stage (share of ears about 50 % in herbage DM) | 35 | 8,1 | 19,8 | 6,38 | 72,3 |
| Whole-crop silage | Early dough stage (share of ears about 40 % in herbage DM) | 27 | 8,8 | 21,2 | 6,31 | 71,1 |
| | Hard dough stage (share of ears about 50 % in herbage DM) | 35 | 8,1 | 20,1 | 6,45 | 72,9 |
| Dry grain | Fully ripen | 88 | 10,6 | 2,6 | 8,39 | 89,1 |
| Corn cob mixture, ensiled | Hard dough stage | 50 | 8,9 | 14,3 | 7,37 | 81,1 |
| * Calculated according to Maynard (1953.), and crude nutrients content and their digestibility according to DLG (1997) | | | | | | |

The high energetic value of the whole-crop maize forage comes mainly from its great NFE content (consisted mainly from starch and sugar), which is in general between 60 and 65 % (in DM), either in maize silage or fresh maize herbage, when harvested from milky grain till the hard dough stage (DLG, 1997). According to DLG (1997), the digestibility of NFE in forage maize is usually between 73 and 78 %. Digestible crude fiber is the second contributor to the energetic value of forage maize. Although the crude fiber content in maize silage (20 to 23 % in DM) is similar to fresh meadow grasses (20 to 25 % in DM, from beginning to mid of tasselling), its digestibility in maize forage (68 to 63 %, from milky to hard dough stage) is lower than in fresh meadow grasses (83 to 77 % from beginning to mid of tasselling).

The superiority of whole-crop maize silage over traditional grass silage is documented in Ireland and England. The whole-crop maize silage was proven as a good replacement for traditional grass silage there because it improved the daily DMI, milk yield and liveweight gains of dairy and beef cattle (O'Mara et al., 1998; Keady et al., 2007 and 2008).

The quality of maize silage depends not only on the developmental stage of maize at harvest, but on the maize genotype as well. The new-come BMR-hybrids of maize offer somewhat tenderer fibers in their stalks and leaves (less lignified and maybe better digested) but they can be more sensitive to drought stress and have to be harvested at the latest until 35 % of DM content (Lewis et al., 2004). Tine et al. (2001) have observed greater DMI, digestibility of TMR and milk yield in cows fed BMR maize silage instead of conventional one in Maryland (USA). The new-come *leafy* hybrids of maize have a lower position of ears on the maize stalk when compared to conventional *grain-type* hybrids. This trait is associated with a lesser share of the thick and hard part of the stalk (below the ear) in the whole-crop herbage, since the above-ear part of the stalk is usually thinner and tenderer. Kuehn et al. (1999) have found better *in-vitro* digestibility of *leafy* hybrid silage when compared to *grain-type* one, but with no significant effects to DMI and milk yields of cows fed alternative silages in Minnesota (USA). Contrary to the conventional *dry-down* maize hybrids, modern *stay-green* hybrids maintain their leaves green and stalk moist even after the hard-dough grain stage. In order to harvest the whole-crop forage at optimum DM content (about 35 %), they may be harvested when the grain is pretty hard, what brings the need for activation of *kernel-processor* in silage harvesters, in order to break the grains' coat (for better digestibility of grains in the digestive tract of cattle).

7.1.1.1.2. Yields of maize forage

Yields vary with climate, soil quality, weather conditions during the maize vegetation period, applied agronomy, cultivated genotype of maize and term of harvest.
In the research conducted in Pennsylvania (the USA, Roth et al., 2003), the whole-crop maize yield of the 30 most popular hybrids averaged 19.6 $t_{DM}$/ha. In colder climates there are expected lesser yields. Gaile (2008) obtained average yields between 13 and 16 $t_{DM}$/ha in Latvia (northern Europe). He seeded his maize in May and harvested it in September. Forage maize yields strongly depend on the weather conditions and soil quality, as observed in the semiarid climate of northeastern Croatia. Namely, in the year 2014 with favorable precipitation, Gantner et al. (2015) obtained a high average yield of 22 $t_{DM}$/ha in the Dalj village, despite the relatively late seeding term (the 29th May), whilst in the previous 2013 year with drought summer Kralik et al. (2015) achieved only 15.7 $t_{DM}$/ha at the same location, despite the earlier seeding term (the 3rd May). Maize forage yields vary with soil quality as well. In the 2014 year, Petričević (2015) obtained about 17 $t_{DM}$/ha on relatively good soil in Babina Greda village, whilst Čunko (2015) obtained only about 10 $t_{DM}$/ha on less fertile acid soil in Veliki Rastovac village, both in the Northeast of Croatia. Expected yields are even lesser at high mountains, mainly due to cooler climate, shorter summer and shallow and less fertile soils. Astier et al. (2006) achieved only about 7 $t_{DM}$/ha in Mexico, on andisol exposed to erosion, at an elevation of 2,300 m a.s.l., after green manuring with vetch. Without green manuring the forage yield was even lesser: 2.5 $t_{DM}$/ha. Their grain yields were very low: 1.5 t/ha and 0.5 t/ha, respectively.
Considering the drought effects in Northeastern Croatia, they can be so detrimental to decrease the yield below half of an average. In such a condition the share of ears and grains in the whole-crop herbages drops to a low level too.
Regarding the term of harvest, any delay brings longer photosynthesis, and therefore the greater yield. However, whole-crop maize shouldn't be harvested beyond 40 % of DM since its herbage becomes too hard for a reliable pressing into a compacted air-tied pile.

7.1.1.1.3. Forage maize agrotechnical measures

7.1.1.1.3.1 Crop rotation

Crop rotation here denotes the temporal sequence of various crops that occupy a certain field or plot. Crop rotation prevents the build-up of populations of specialized crop pests on a certain agricultural plot or field. These pests include phytophagous arthropods, nematodes and vertebrates, phytopathogenic fungi and bacteria, and specialized weeds. Therefore it is very beneficial to rotate crops that belong to various botanical species or (even better) to various botanical families. Crop rotation is strongly recommended for maize even though maize was historically, sometimes and in some places, successfully grown in temporal monoculture for several years. The main pest in temporal monoculture nowadays is a western corn rootworm (*Diabrotica virgifera virgifera* LeConte), which can cause significant damage to maize roots through larval feeding. It overwinters in the soil where maize was grown the last vegetation year, in the form of a deposited egg. After hatching the next spring, larvae search for new maize roots nearby and feed on them thus making the damage. Attacked maize plants have weakened roots, and strongly attacked plants lodge.

7.1.1.1.3.2. Soil tillage

Considering the soil tillage, in Europe still prevails conventional ploughing as the first operation. It enables for good coverage of previous crop residues and weeds with soil, and also for incorporation of organic and mineral fertilizers. Plowing makes a great volume of cracks and pores in the soil which act as an accumulator of precipitated water (rain, snow). However, there appear some serious objections to conventional plowing: 1) it is associated with excessive aeration of the arable layer that leads to a loss of humus, what in further causes a loss of stabile soil structure and leads to soil compaction; 2) leaves the soil uncovered for some time, thus enhancing the soil erosion by rain-water and wind; and 3) consumes a vast of energy required for cut and inversion of the arable layer. Therefore, not so recently, appeared some reduced tillage (non-inversional chisel tillage, shallow inversional disking and their combinations) and no-till practices for maize and other arable crops cultivation. They have brought some energy savings and, in the case of no-till, the permanent soil coverage (made of residues from the forecrop) which somewhat decreases the soil erosion. Though, there seems that plowing can provide for the least weed problems. In a 35-year long field trial of three soil-tillage variants (plowing to 20-25 cm, chisel tillage and no-till) in Ohio (USA), Cardina et al. (2002) have found the least number of weed seeds in the plowed soil, while the no-till had the greatest number of weed seed. Similarly found Demjanova et al. (2009) in Slovakia in their seven-year trial: soil under reduced tillage had more than double weed plants than soil under conventional plowing to the depth of 30 cm. Three-year field research conducted in Baranja (the Northeastern Croatia, semiarid climate) has pointed that maize crops grown on plowed soil are less prone to drought effects when compared to reduced tillage or no-till. Namely, Jug et al. (2006), in a droughty 2000 year, observed the greatest maize grain yield on the autumn-plowed soil (7.8 t/ha), the lower yield on the autumn-disked soil with spring seedbed preparation (5.3 and 5.9 t/ha), and the lowest yield at no-till variant (0.8 t/ha). In a year with favorable precipitation (1999) all the variants had similar grain yields (about 10 t/ha).

Autumn-plowed soil in temperate climates usually overwinters in the farrow. Farmers after winter usually level their fields (when the soil has become dry enough to carry the tractors), and undertake the seedbed preparation, usually immediately before the seeding term. Besides creating a layer for seed deposition, seedbed preparation often destroys the emerged weeds, thus helping further weed control. In the absence of soil tillage farmers sometimes apply total herbicides to control the weeds before seeding maize. Reliance on chemical weed control in no-till agronomy for maize is almost necessary because interrow cultivation is omitted there too.

7.1.1.1.3.3. Fertilization

Due to its great herbage mass, maize uptakes a great quantity of minerals for its nutrition (Table 11).

Table 11. Projection of plant nutrition minerals uptake in the whole-crop forage maize, in the developmental phase of doughy grain, according to the concentrations of minerals reported in NRC (1996)

| | Expected natural yield (*as it is*) | 30 t/ha | 40 t/ha | 50 t/ha | 60 t/ha |
|---|---|---|---|---|---|
| | Expected DM yield | 10 t/ha | 13,3 t/ha | 16,7 t/ha | 20 t/ha |
| Mineral | Content in DM (%) | Uptake (kg/ha) | Uptake (kg/ha) | Uptake (kg/ha) | Uptake (kg/ha) |
| N | 1,28 | 128 | 171 | 213 | 256 |
| P | 0,22 | 22 | 29 | 37 | 44 |
| K | 1,14 | 114 | 152 | 190 | 228 |
| Ca | 0,25 | 25 | 33 | 42 | 50 |
| Mg | 0,18 | 18 | 24 | 30 | 36 |
| P and K uptake, expressed as oxides | | | | | |
| $P_2O_5$ | | 50 | 67 | 84 | 101 |
| $K_2O$ | | 137 | 182 | 228 | 274 |

Targeted maize yields of modern farmers are usually greater than the soils' indigenous supply of minerals can afford. Therefore modern farmers use mineral and organic fertilizers with aim to supplement the soils' indigenous supply. Among the mineral nutrients that are being amended, nitrogen (N) is generally considered the most yield-contributing one. Recommendations for mineral N fertilization are usually based on projections of nitrogen release from soils' organic matter mineralization plus mineral nitrogen reserve in arable and sub-arable layers (in the reach of maize roots) in spring. In the main maize cultivation areas of Croatia, official recommendations often advise doses between 200 and 230 kg/ha of pure nitrogen. According to somewhat elder reports (Mesić et al., 2003), there is required 150 to 200 kg/ha of pure nitrogen to achieve maximum or near-maximum maize yields in continental Croatia. Such a range of N-fertilization doses could probably be suitable in most areas where maize is grown, and where expected grain yields are about 10 t/ha (or corresponding whole-crop silage DM yields near 20 $t_{DM}$/ha). Lower doses could be suitable for exceptionally fertile soils (soils with great indigenous nitrogen supply, i.e. soils with high humus content and abundant biological activity), for plots recently manured with farm-yard manure (FYM), and for maize succeeding the legume crops (lucerne, clover, soybean, pea, etc.). Higher doses would be required for greater targeted yields, and less fertile soils, but only if they have sufficient capacity to hold mineral nutrients. However, producers should be aware that high dosage of N-fertilizers does not guarantee high yields in stress conditions (e.g. drought during maize vegetation), while the favorable conditions (e.g. optimum rainfall and temperatures) during the maize vegetation can provide for high maize yields even when modestly fertilized. Total aimed N-fertilization should be split into a few portions to diminish the N-losses due to leaching and volatization. It is usually split into: 1) small portion in the preceding autumn, given as Urea (46 % N); 2) greater portion given in seedbed preparation, usually in the form of Urea; and 3) smaller (or two) portion(s) given in side-dressing(s) in the form of ammonium-nitrate (AN 33% N or KAN 27 % N). Regarding the P and K fertilization, recommendations are often based on the AL-method (soil P and K extracted by mixture of acetic and lactic acid) or on Bray- or Olsen-extract method. Readings of AL-method for $P_2O_5$ between 15 and 20 mg/100 g of dry soil are considered "good", while for $K_2O$ "good" is between 20 and 30 mg/100 g of dry soil. When readings fall into the "good" range, Vukadinović and Bertić (2013) recommend fertilizing the soil with P and K amounts that are equal to their removal from the soil with planned yield. When the soil has greater P and K levels, the fertilization should be lesser, and vice-versa.

Since forage producers usually rear their livestock, they are expected to have plenty of farm-yard manure (FYM). FYM is a mix of dung, urine, and straw for bedding, all-together fermented for at least six months, with about 25 % of DM content. Maize is one of the highest-yielding crops and therefore it should have a priority for the distribution of FYM. The usual dosage of traditional FYM for the maze was between 30 and 40 t/ha, and nowadays is up to 34 t/ha in Croatia due to nitrate directive regulations. Historically, FYM contained on average about 0.6 % of N, 0.32 % of $P_2O_5$ and 0.7 % of $K_2O$ (Mihalić, 1985), but in newer research it contained about 0.8 % N, 0.43 % $P_2O_5$ and 1.18 % $K_2O$ (Cvjetković et al., 2014). FYM richer in dung and urine is richer in plant nutrients, while the one richer in straw has poorer nutrients content. FYM dosage of 34 t/ha would bring about 200 kg/ha of N, 110 kg/ha $P_2O_5$ and 240 kg/ha $K_2O$. Half of these nutrients would likely be released for plant nutrition during the first year from FYM application (Mihalić, 1985), i.e. for maize nutrition. In a Nebraska-located trial, Eghball and Power (1999) revealed that maize yield with solely mineral N-fertilization has exceeded solely FYM fertilized maize only in drought years. Therefore the authors deem that additional mineral fertilization over a full-dose FYM for maize would probably give a little advantage in yield, except in the case of lack of rainfall during maize vegetation. Eghball and Power (1999) revealed that maize herbage contained significantly more nitrates when the soil was fertilized with mineral N instead of FYM, and that in extreme drought years nitrates exceeded the acceptable concentration.

7.1.1.1.3.4. Seeding

Maize is a warm-season cereal that requires a frost-free vegetation period. For quick emergence, the soil temperature in the seeding layer should be at least about 10°C (Kovačević and Rastija, 2015). Therefore the recommended seeding term in continental Croatian conditions arrives in mid of April. At more southern latitudes it comes earlier and in more northern later. There is recommended to seed the maize as earlier possible to pass the most sensitive phases of maize development (tasselling and silking) before the onset of eventual summer heat and drought. In some areas (like in northeastern Croatia) a mid-spring drought can dry-out the soil's seeding layer so this can be a reason to seed the maize earlier too. However, even in semiarid north eastern Croatia, a successful high-yielding maize crop can be established much later, until the end of May (Gantner et a., 2015) because in the most of years there come sufficient rains from the end of May till the end of July. The second half of April Croatian forage producers usually name "main seeding term" because it enables for full length vegetation and maximum yields of maize, while the May is usually named "subsequent seeding term" because maize than usually follows some winter forage (temporal) intercrops, like small-grain cereals (winter wheat, oats, ray, barley, triticale) and their mixes with cool-season annual legumes (forage pea, vetches, crimson clover). Choice FAO group (i.e. of vegetation length) of the seeded maize cultivar should be adjusted to the seeding term: later cultivars for earlier seedings and earlier cultivars for later seeding, to achieve a proper ripeness (doughy to hard-dough grain or about 35 % of DM content in maize herbage) by the end of summer. Seeding depth is at about 5 cm (in dry conditions deeper, and wet shallower). Maize is a row crop with the usual inter-row distance of 70 to 75 cm. In-row distance between plants is usually adjusted to achieve the recommended crop stand (mainly between 6 and 8 plants per $m^2$). Some producers plant their forage maize at a denser crop stand (up to 20 %) in order to achieve higher forage yields. However, this can be associated with somewhat lesser grain content in the whole-crop silage, and with somewhat poorer drought tolerance of maize. The choice of maize cultivar is an important decision before planting maize. It's probably best to seed the well-accepted cultivars. However, novel GM-hybrids offer somewhat simpler chemical weed control due to Roundup-Ready trait (RR-hybrids) and/or lesser European maize borer (*Ostrinia nubilalis* Hübner) damages due to Bt-trait (Bt-hybrids). Though, there are on the rise problems considering the achieved resistance of weeds to Roundup herbicide and of insects to Bt-toxins in GM-maize.

7.1.1.1.3.5. Nursing

Inter-row cultivation is the most important nursing measure in maize production. It cuts the weed in inter-row space, aerates the surface soil layer thus enhancing the appreciated microbiological activity in the soil, breaks the capillary flow of soil water to its surface where it is being lost due to evaporation, and makes the soil more porous to accept and contain the precipitated rainfall during the maize vegetation. Beneficial consequences of inter-row cultivation quickly become visible due to faster growth and greener leaves of cultivated maize. Kovačević and Rastija (2015) advise at least two inter-row cultivations: the first one when maize has three to four leaves developed, and the second one when seven to eight leaves are developed. Planting maize in mulched soil can be beneficial too. According to the review of Oblačić et al. (2012), winter cover crops when cut and left to cover the soil provide for more favorable microclimate and microbiological activity in the soil below their mulch, thus enabling for higher maize yields than when maize was grown on bare soil. However, through such a soil cove, maize can be seeded only with the use of no-till seeding machines.

7.1.1.1.3.6. Crop protection

In many regions the most serious threat to maize yield are weeds. Some preventive measures include good field hygiene (cultivation of the preceding stubble to kill the weeds before their seeds mature and to exhaust the rhizomes of perennial weeds) and false seedbed preparation about 10 days before the real seedbed preparation. Weed control in maize can be done by mechanical measures, like inter-row cultivation and hand-hoeing, and/or by chemical treatments (i.e. use of herbicides). When using herbicides, it is crucially important to apply a recommended dosage at a proper developmental phase of maize and weeds. Generally, younger weeds are more easily killed with herbicides. Considering the choice of a proper herbicide, it is important to know which weed species appeared in maize because herbicides are not universal. Some herbicides control narrow-leafed weeds (weeds from grass family), while others control broad-leafed weeds (many dicotyledonous weed species). Translocational (systemic) herbicides are required to control weeds that emerged from rhizomes and greater weeds emerged from seeds, while the contact herbicides can control only weeds that emerged from seeds, while in early developmental stages. Some herbicides act on weed seedlings before their emergence on the soil surface (so called “soil applied herbicides”). They have to be introduced into a surface soil layer by light rain after they are sprayed over the field. There are some successful recent developments of robotized weed control machines for row crops that can distinguish the crop plants from weeds. Often used criteria for distinguishing are differences in plant height between crop and weed, and differences in leaf shape.
Young seedlings of maize can be attacked by *Elateridae* soil worms and by birds (e.g. pheasants). Seed coating with insecticide can protect against worms and bird-repellents against birds. Maize roots can be attacked by western corn rootworms, but the damages can be successfully prevented by a proper crop rotation. Caterpillars of European maize borer can bore maize stems and cause lodging, but plowing-under the previous year’s maize stover prevents the butterflies to emerge.

7.1.1.1.3.7. Harvest

Silage maize is usually harvested by silage harvesters (Figure 3) that cut and chop above-ground maize herbage. The average length of cut particles is usually between two and three cm. According to Bal et al. (1997), optimum quality of the whole-crop maize silage is achieved when maize is harvested at about 35 % DM content, what coincides with doughy to the hard-dough kernel in conventional *dry-down* maize, or when the milk-line at 2/3 of maize kernel. Harvesting when forage has less than 30 % of DM leads to silage with acidic smell due to excessive acetic acid content, while over 40 % of DM in harvest leads to difficult compaction of maize particles, remnants of air in a silage pile and consequential spoilage. The time frame adequate for ensiling usually lasts about two weeks (Ivana Selthofer, Belje d.d., Northeastern Croatia, personal communication, unpublished data). The height of the cut (from the soil surface) is usually between 20 and 50 cm. The higher cut is associated with lesser harvested yield but also with better forage quality (i.e. with the lesser partition of hard fibers from the bottom of maize stalk and higher partition of grains which are rich in starch). Harvesting should be performed when the weather is dry and when there is no mud on the soil.

Figure 3. Harvesting forage maize near Vukovar, Northeastern Croatia (photo: Ranko Gantner, 2010)

Karsten et al. (2003) showed that forage maize can be harvested by grazing heifers in the silking stage of maize, thus providing high-quality forage (about 13 % CP in DM) during summer to complement the lack of forage from perennial pasture, or even in the milky-doughy stage of maize, thus saving the costs required for harvest and filling the silos.

7.1.1.1.3.8. Associations with annual legumes and other species

Planting forage maize in association with soybeans in Massachusetts (USA) has brought somewhat higher crude protein (CP) content but lower DM yield when compared to the pure maize crop (Herbert et al., 1984). Climbing beans (*Mucuna pruriens* L., *Lablab purpureus* L. and *Phaseolus coccineus* L.) did not decrease the forage yield when were associated with forage maize in Wisconsin (USA) but slightly increased CP content when compared to pure stand forage maize (Contreras-Govea et al., 2009). Similar was found for *Vigna unguiculata* L. and climbing *Phaseolus vulgaris* L. in Turkey by Geren et al. (2008). Association of sunflower with forage maize in Ottawa (Canada) brought lesser forage yield and lesser digestibility than pure stand maize (Warren, 1980).

7.1.1.2. Forage sorghum

Sorghum (Figure 4, *Sorghum sorghum* L.) is an annual crop that requires more heat than maize. For quick emergence it needs at least 13°C in the seedbed layer (Erić et al., 2004). Forage sorghum's yield capacity is similar to forage maize when grown in conditions adequate for high maize yields. Its advantages come visible in more stressful conditions. It generally tolerates drought, heat and less fertile soils better than maize. Therefore, it is usually grown in areas where such stresses limit the maize yield. It is rarely accepted in areas where maize gives satisfactory forage yields, mainly due to the fact that its energy value for ruminants is lower than that of maize. The cause for lower energy value lies in the fact that forage sorghum contains lesser grain partition in the whole-crop forage yield, and therefore lesser starch content. However, it can be appreciated for late seeding terms because it can build a high forage yield in a shorter vegetation period than maize.

Forage sorghum's agronomy is similar to maize, with some particularities: in temperate zones seeding should be somewhat later, to get the warmer seedbed layer, crop stand density should be 20 to 25 plants per m$^2$, and soil fertilization should be smaller than for maize (only 100 to 150 kg of N per ha, Chobotova and Babić, 2013). It should be harvested at about 35 % of DM for the whole-crop silage, just like maize. It can be fed as a fresh green forage to ruminants and even to swine when herbage is fully green and soft (it is sweet then), but it must be taller than 60 cm in order to avoid HCN poisoning of livestock. Unlike maize, some sorghum cultivars can have good aftermath upon cut or grazing.

Figure 4. Forage sorghums in an experimental plot near Dalj village, north eastern Croatia (photo: Ranko Gantner, 2013)

7.1.1.3. Sudangrass

Sudangrass (*Sorghum sudanense* L.) is a relative of forage sorghum, with many traits and visual appearance similar to sorghum. It is appreciated as a summer fresh green forage or pasture because of its high forage quality when vegetative (about 70 % of TDN and about 16 % of CP in DM) and good summer growth, when cool-season grasses fall in their summer dormancy. Its main particularities, when compared to sorghum, are thinner stem, the greater share of leaves in the herbage, and very good regrowth after defoliation (cut or grazing) (Figure 5). It is generally used in the vegetative stage, before tasselling or earlier, but always when taller than 50 cm (to avoid HCN poisoning of livestock). Young aftermath also has to exceed the mentioned height. If used after tasselling, its quality drops, and the main quality advantage over forage sorghum is being lost. On the seed market there are available interspecies crosses of forage sorghum and sudangrass, which offer somewhat higher yields. DM yield capacity of sudangrass × sorghum hybrids, when harvested before tasselling, is likely near half of the forage sorghum yield, but it can be even lesser in drought conditions since the cut (or grazed) plants suffer more until they rebuild their foliage. Sudangrass × sorghum hybrids can give three growths (or cuts) in continental Croatian conditions during the vegetation period (from May till September). Sudangrass herbage can be conserved in the form of silage, haylage or hay, while the sudangrass × sorghum hybrids probably have a too thick stem for hay preparation.


Figure 5. Sudangrass × sorghum hybrid - first growth advanced to tasselling and nearby aftermath during summer, north eastern Croatia. Photo: Ranko Gantner, 2013.

The agronomy of sudangrass is similar to forage sorghum, but the recommended crop stand is much denser - 150 to 600 plants per m$^2$ (Erić et al., 2004). A much thinner stand is required for sudangrass × sorghum hybrids – 30 to 35 plants per m$^2$ (Chobotova and Babić, 2013). Both of them are being cut or grazed when vegetative, or at the latest in tasselling.

7.1.2. Cool-season cereals

Among the cool-season cereals grown for forage, there are primarily wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), rye (*Secale cereal* L.), barley (*Hordeum vulgare* L.) and wheat × rye interspecies hybrid *triticosecale*. These species are members of the grass (Poaceae) family too. They are worldwide grown primarily for grain production for human consumption and livestock feed (as concentrates rich in starch, i.e. energy). They prefer somewhat cooler environments for a good growth, like a colder half of a year in temperate and mediteranean zones, but in cooler climates (in zones closer to the Earth's poles and at higher mountains) they are grown in a warmer part of the year. In temperate and mediteranean climatic zones they usually complete their vegetation by the onset of summer heat and drought. There they are appreciated for forage production since they utilize the colder half of a year for building-up their forage yield, during the very same period when the most productive warm-season forages (maize and sorghum) cannot thrive. Thus, by combining the cool-season and warm-season cereals in a succession on the same plot, foragers obtain two harvests in a single production year, with significantly improved annual (this way cumulative) yield. In mediteranean climates, cool-season cereals can provide greater forage yields (in a single cut) than can (there traditional) Italian ryegrass (*Lolium italicum* L.) because summer drought limits the summer regrowth of ryegrass. However, cereals have thicker and harder stem than Italian ryegrass in analogous developmental stages, what makes them inferior considering the forage quality. To improve the forage protein content and save the costs for nitrogen fertilizers, cool-season cereals are mostly grown in association with cool-season annual legumes (Figure 6), like forage pea (Austrian winter pea) and vetches, and rarely with (annual) crimson clover (*Trifolium incarnatum* L.). Besides their use for harvested forages (silage, haylage and hay), they are used for grazing too, usually during the tillering and early stem elongation. Wheat can often be dual-purpose utilized, for grazing and the final grain harvest. If grazing is terminated before the beginning of stem elongation, there can be expected very little sacrifice of the final grain yield. The straw of cool-season cereals is commonly used for bedding under livestock. Sometimes it is used as a feed, specifically in the cases of forage shortages or to bring the necessary fiber in ratios too rich in concentrated feeds.

Figure 6. Association of winter forage wheat and winter forage pea, cut at beginning of May, north eastern Croatia. Photo: Ranko Gantner (2011.)

The most important developmental stages of cool-season cereals (Figure 7) are:

1. seedling growth
2. tilling (initiation of additional tillers beside the main shoot)
3. stem elongation (from this phase the growth is visible daily)
4. booting (flag leaf sheath extending and opening)
5. ear emergence
6. flowering
7. milky grain
8. doughy grain
9. ripening grain


Figure 7. Most important wheat development stages

Stages until the ear emergence are considered vegetative since there are no visible reproductive organs, and from the ear emergence are called generative ones.

7.1.2.1. Feeding value of cool-season cereals forage

The highest crude protein content and energy value of wheat forage is in its earliest developmental stages, when vegetative (Table 12), with decline along the succession of developmental stages.

Table 12. Parameters of wheat forage quality according to various sources

| Source | Wheat development stage | DM (%) | CP (% in DM) | CF (% in DM) | NEL (MJ/kg of DM) | TDN* (% in DM) | pH |
|---|---|---|---|---|---|---|---|
| Wheat pasture, Brazil (Pitta et al., 2011) | Young vegetative | | 21,2-24,2 | | | 73,5 | |
| Fresh green forage, Germany (DLG, 1997) | Ear emergence | 21 | 13,3 | 22,9 | 6,72 | 74,1* | |
| | End of flowering | 25 | 10,0 | 34,3 | 5,48 | 63,9* | |
| | Doughy grain | 30 | 8,9 | 30,0 | 5,46 | 63,5* | |
| Silage, Germany (DLG, 1997) | Ear completely emerged | 21 | 11,5 | 30,8 | | 62,5* | |
| | End of flowering | 25 | 10,8 | 34,6 | 5,04 | 59,3* | |
| | Doughy grain | 30 | 9,5 | 29,1 | 4,97 | 58,3* | |
| Silage, Italy (Crovetto et al., 1998) | Boot | 20 | 12,7 | 29,6 | 7,74 | | 3,60 |
| | Midbloom | 22 | 9,8 | 31,1 | 6,41 | | 3,55 |
| | Milky grain | 29 | 8,3 | 28,9 | 5,69 | | 3,60 |
| | Doughy grain | 36 | 7,9 | 26,7 | 5,39 | | 3,80 |
| * Calculated according to Maynard (1953.), and crude nutrients content and their digestibility according to DLG (1997) | | | | | | | |

Whole-crop wheat silage satisfactory replaced the Italian ryegrass silage for dairy cows in Portugal (Fonseca et al., 2005) and perennial ryegrass for beef steers in Great Britain (Keady et al., 2007), thus proving that it can be an acceptable alternative. Silage of the whole-crop wheat plus forage pea mixture has satisfactorily replaced the perennial ryegrass silage for dairy cows in Great Britain too (Salawu et al., 2002). Crop association of forage wheat and forage pea can raise the CP content to the level of about 15 % in DM (Hakl et al., 2011; Salawu et al., 2001; Stjepanović et al., 2008).

7.1.2.2. Forage yield of cool-season cereals

Forage yield strongly depends on the cutting term, i.e. on the development stage of plants. DM yield is being accumulated continuously until the end of vegetation. Besides, the soil fertility, weather conditions and applied agronomy affect the yield too. Table 13 shows the obtained whole-crop wheat yield by two researchers. There can be generally said that forage wheat, when harvested from flowering till milky grain yields between 8 and 10 $t_{DM}$/ha, if grown at favorable soil and weather conditions and appropriate agronomy (it is necessary to grow tall-stature varieties, with stem height above 1 m in earing).

Table 13. Whole-crop wheat DM yield in Italy and Greece

| | Forage DM yield (t/ha) | | | |
|---|---|---|---|---|
| The development stage of wheat | Flag leaf | Mid flowering | Milky grain | Doughy grain |
| Crovetto et al. (1998), Italy | 3,36 | 5,01 | 6,95 | 9,60 |
| Lithourgidis et al. (2011), Greece | | | 11,69 | |

On deep fertile soils and in the temperate semiarid climate of northeastern Croatia, forage yield of crop associations of winter wheat and pea can usually be between 8 and 10 $t_{DM}$/ha during the first half of May (Stjepanović et al., 2008; Gantner et al., 2017), when wheat is from the flag leaf to the end of flowering stages, and pea is in flowering. However, the late seeding term in preceding autumn (beginning of November), followed by delayed and cold spring, can postpone the yield build-up and decrease the yield (Gantner et al., 2016).

#### 7.1.2.3. Agrotechnical measures for cool-season cereals forage production

Agronomy for forage production from cool-season cereals is very similar to the one used in grain production, with main differences considering the choice of the cultivar (it has to be tall-statured, above 1 m in earing stage), harvesting technique (they are being cut just about several centimeters from ground level, and mostly chopped by silo-combine harvester) and harvesting term (they are usually harvested between flag-leaf and milky-grain stages). Very often these cereals are grown in associations with annual cool-season legumes to increase the protein content in forage produced, and to save on N-fertilizers, since such associations can give satisfactory yields without the use of mineral N-fertilizers (if a sufficient share of legume is achieved). When grown in associations with annual forage legumes (pea and vetches), cereal stand density is often recommended to be halved, to enable the satisfactory growth of associated legumes, and their sufficient share in the mixture yield (30 to 50 %). In such mixtures, forage pea is usually seeded at a density of 100 to 150 live seeds per $m^2$, and vetches at about 230 live seeds per $m^2$. Temporal cutting term is usually adjusted to enable a subsequent warm-season forage cereal seeding. Shift between cool-season and warm-season forages in northeastern Croatia occurs usually during May. Considering the particularities of cool-season cereal species, there is an obvious difference for rye – it starts the growth earlier in spring, but becomes harder earlier too, and therefore it is recommended for utilization till the flag-leaf phase (Ditch and Bitzer, 1995). Authors have observed that rye outcompeted the associated forage pea in a mixture (Gantner et al., 2017).

## 7.2. Annual legumes for forage production

Legumes are much appreciated in forages production since they are richer in protein content than cereals, and they are very often independent of mineral nitrogen fertilization for achieving the targeted yields. This trait is the consequence of their symbiotic relationship with nitrogen-fixing bacteria that usually inhabit the root nodules of legumes.

### 7.2.1. Cool-season annual legumes

These legumes best grow in cool and moist conditions (the first half of the spring), and they usually approach the end of their vegetation period at the beginning of the summer. They are usually sensitive to heat and drought, which decrease their yields. The most important cool-season annual legumes for forage production are forage pea and forage vetches.
Forage pea (*Pisum sativum* L. var. *arvense*) is mainly grown as an overwintering crop in temperate regions, and in American literature is referred to as Austrian winter pea. Unlike its gardening relative, the forage pea has a very long stem (about 150 cm long), which is unable to stand alone. Therefore it requires some support, which is mainly some winter cereal. Its agrotechnical measures are very similar to those applied for winter forage cereals, and it comes into the optimal stage for cutting simultaneously with winter cereals. Therefore these two forage crops are usually grown as companion crops. Cereals usually provide for a greater yield, energy and support, whilst the pea increases the protein content and brings diversity into produced forage. The targeted share of pea in the cereal-pea mixture yield is usually 40 to 50 % (on a DM

basis). To achieve such a share of a pea, its seeding rate in a mixture with the winter wheat should be about 150 seed/m$^{2,}$ whilst the seeding rate of cereal should be half of the pure stand. In Croatia, forage pea is mainly grown as a winter crop in association with winter wheat. It is usually seeded in October and the mix is mowed in May, mainly for the haylage production.

Besides forage pea, the dry pea production becomes increasingly attractive because the dry pea grain can be fed to livestock without prior thermical treatment, i.e. directly or after grinding. It is considered a protein and energy rich concentrated feed due to its high protein and starch content. In continental Croatian conditions it yields from 3 to 4.5 t/ha of high-quality grain. It is usually grown as a spring-seeded crop that completes its vegetation at the beginning of July.

Forage vetches are somewhat forgotten in Croatian practice. Their value and agrotechnical measures are very similar to the forage pea. Vetches seeds are much smaller than of forage pea, and cannot be fed to livestock due to their toxicity.

## 7.3. Perennial legumes

Perennial legumes may be considered as "fine-stemmed" forages when compared to forage cereals, especially to forage maize or sorghum. The diameter of their stem is usually up to few millimeters, while sorghum's and maize stem can be wider than few centimeters. Therefore they are much closer to the natural feed of herbivore livestock. Perennial legumes are especially appreciated in livestock nutrition because of their relatively higher crude protein concentration when compared to forage cereals and perennial grasses. Moreover, they comprise more calcium and magnesium than forages from the grasses family. Besides the quality-related advantages, their agronomical importance stems from their longer exploitation period (for at least a few years), good annual forage DM yields, and better drought tolerance and summer growth when compared to cool-season perennial grasses

### 7.3.1. Cool-season perennial legumes

#### 7.3.1.1. Lucerne (alfalfa)

According to the presence and share in TMRs for cattle feeding, lucerne (alfalfa, *Medicago sativa* L., Figure 8) has become a "number two" forage in many arable regions, following the silage maize being the "number one". The reasoning for it lies in the facts that lucerne, with its high CP content, complements the lack of CP in silage maize, and that the lucerne gives a good and reliable annual forage yield, even in semiarid climates. The northeast Croatia (temperate zone with semiarid continental climate) lucerne is considered the most drought-resistant forage crop. It is being fed mostly in the forms of hay and haylage, and rarely as *cut-and-carry* fresh green herbage, pasture, and dehydrated pellets or flour. Thanks to its thinner stem, it can be cut into longer particles than silage maize (particles of a few to several cm long) before feeding to stimulate rumination. Long exploitation period (nowadays for about four years, Halagić et al., 1992) of lucerne crop provides for a small annual depreciation of the crop establishment costs (about ¼ of the total establishment costs). In favorable growth conditions and with the proper regime of utilization lucerne crop can last for longer than 10 years (Halagić et al., 1992). It was traditionally called "(*djetelina*) *sedmakinja*" or "(*djetelina*) *konjarica*" by Croatian peasants, which meant "*seven-year-clover*" or "*horse-clover*". Before the advent of silage maize, lucerne was the primary forage in European arable regions with adequate soil quality. It was introduced into Croatia in the 18th century (Stjepanović et a., 2009), where it has replaced red clover and semi-natural meadows in hay production, if sufficient soil quality is provided. Lucerne is nowadays appreciated for grazing in areas with a semiarid climate, like for dairy cattle in Argentina

(Cordoba, Pampas; Colline et al., 2005, cit. Baudracco et al., 2011) and the southern island of New Zealand (Smith et al., 2013), where the sheep are grazed on lucerne too.

With the aim for better understanding of the further text here we present the most important development stages of lucerne:

1. seed germination
2. the emergence of cotyledons above the soil surface
3. appearing of the 1st true leaf with a single leaflet
4. appearing of the 2nd true leaf with three leaflets
5. vegetative growth and appearing of secondary shoots' buds
6. vegetative growth of primary and secondary stems
7. the appearance of flower buds (budding in the further text)
8. flowering (bloom)
9. fertilization, pods formation, enlargement of seeds in green pods
10. seed ripening, pods become brown.

Stages before the appearance of reproductive organs (before flower buds visible) are called vegetative, whilst the later ones are reproductive (Figure 8).

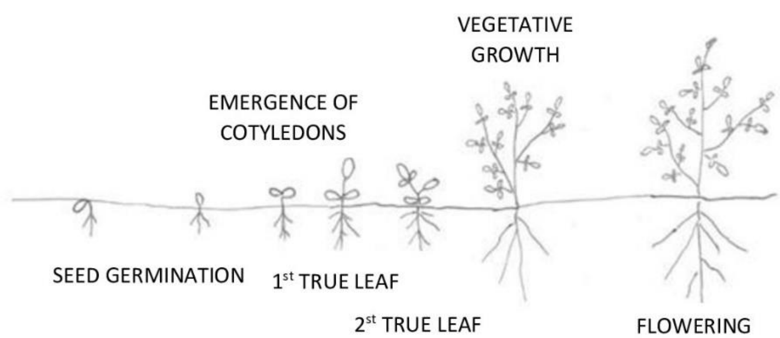



Figure 8. Developmental stages of lucerne till the appearance of flower buds

7.3.1.1.1. Feed value

Lucerne comprises relatively high CP content in fresh herbage until the end of flowering and in the hay if cut till budding (Table 14). Its energetic value is significantly lower than that of maize silage, but can be quite good in fresh green forage before the budding stage.

Table 14. Feed value of lucerne in various forms of forage (DLG, 1997)

| Forage | Faza razvoja lucerne | DM (%) | CP (% in DM) | CF (% in DM) | $NE_L$ ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Fresh green forage, 1st spring growth | Before buding | 15 | 25,4 | 17,8 | 6,33 | 68,7 |
| | Budding | 17 | 21,9 | 23,8 | 5,82 | 64,4 |
| | Begin of bloom | 20 | 18,7 | 28,6 | 5,49 | 62,1 |
| | Mid to end of bloom | 23 | 17,5 | 32,7 | 5,07 | 58,1 |
| | Off bloom | 27 | 16,3 | 36,5 | 4,71 | 54,7 |
| Silage, 1st spring growth | Before buding | 35 | 21,1 | 18,7 | 6,00 | 66,4 |
| | Budding | 35 | 20,7 | 25,4 | 5,43 | 61,3 |
| | Begin of bloom | 35 | 17,9 | 29,4 | 5,04 | 57,8 |
| | Mid to end of bloom | 35 | 17,8 | 34,2 | 4,70 | 55,1 |
| | Off bloom | 35 | 16,0 | 38,6 | 4,51 | 53,2 |
| Hay, 1st spring gtowth | Before buding | 86 | 20,8 | 21,1 | 5,36 | 59,8 |
| | Budding | 86 | 19,2 | 27,6 | 5,18 | 58,9 |
| | Begin of bloom | 86 | 16,5 | 32,6 | 4,89 | 56,3 |
| | Mid to end of bloom | 86 | 16,4 | 36,6 | 4,60 | 53,5 |
| | Off bloom | 86 | 15,7 | 41,0 | 4,21 | 49,9 |

* Calculated according to Maynard (1953.), and crude nutrients content and their digestibility according to DLG (1997)

Lucerne in conserved forms (silage, hay) has lower CP and energy because of losses that occur during the ensiling and curing. Quality can dramatically drop below the values reported in the table above in cases of adverse weather conditions during hay curing on the ground (rain) and mistakes during hay-making (raking, tedding, or baling in hot and dry conditions causes the detachment and drop of leaves from the stems, so finally only the stems become collected).

Despite the high CP content and its digestibility in lucerne, there is not a guaranteed high utilization rate of lucerne proteins, mainly because of rapid lucerne proteins decomposition in the rumen, which is faster than intake into rumen's microbial biomass. The addition of forages rich in tannic compounds (bird's foot trefoil and sainfoin; Aerts et al., 1999; Mina et al., 2003) can slower the protein degradation and synchronize it with intake into microbial biomass. Better utilization of degradable proteins can be achieved probably by the addition of readily available carbohydrates too (Miller et al., 2001).

Lucerne haylage or silage fed as the sole forages in TMRs for Holstein cows in early lactation in Wisconsin (the USA, Hoffman et al., 1997) enabled for high milk yield, from 29 to 32 kg/cow/day (based on 4 % milkfat). Though, TMR had a high share of concentrate: 42 to 50 % in DM. Concentrate comprised mainly maize grain (60 to 80 %, DM basis) and soybean meal. In the comparative feeding trial of lucerne haylage vs. perennial ryegrass haylage, milk yield of Holstein cows in peak lactation (61 days in milk plus 28 days of trial), in Wisconsin too (Hoffman et al., 1998), was similar between variants: about 29.4 kg/cow/day. The share of concentrates in TMRs was lower here, about 31.5 % (DM-based), and concentrates mainly comprised maize grain (about 67 %, DM-based) and soybean meal (about 20 %). TMRs were adjusted to 20 % CP in DM and 6.7 $MJ/kg_{DM}$ of $NE_L$. Crossbred Friesian×Jersey cows at beginning of lactation, grazed on pure lucerne in Canterbury (New Zealand; Smith et al., 2013), yielded 25.3 kg/cow/day of milk, whilst on pure perennial ryegrass pasture yielded 26.4 kg/cow/day. Milk fat content was about 5 % and protein about 3.7 % without significant differences between lucerne and ryegrass grazed cows. Cows were assigned the daily pasture allowance of 17 $kg_{DM}$/cow/day above the residual herbage mass of 1500 $kg_{DM}$/ha, without concentrate supplementation. Holstein cows in mid-lactation grazed on lucerne – cocksfoot (*Dactylis glomerata* L.) mixture in Indiana (the USA, Jones-Endsley et al., 1997) were supplemented with 6.4 or 9.6 kg of concentrates and yielded about 21.5 kg/cow/day of milk. Pasture DMI was about 12 $kg_{DM}$/cow/day. Angus steers grazed pure lucerne in Argentina exhibited liveweight ADG between 0.16 and 1.01 kg/head/day (Berone et al., 2020). Greater ADGs were achieved when steers grazed younger lucerne, and poorer on older lucerne, probably because young lucerne was richer in energy. The authors didn't report any bloat in steers, neither application of preventive agents. We therefore suppose they carefully handled steers in order not to enter a new paddock when hungry, and doing their removal during the afternoon. Charolais and Simmental×Hereford steers grazed lucerne – grass mix (70 % : 30 %) in Manitoba (Canada, Popp et al., 1997) without supplementation and achieved ADGs between 0.68 and 1.49 kg/head/day. Variations in ADGs were mainly due to the effects of different years of research (climatic aberrations). Parda de montaña steers achieved the liveweight ADG 1.3 kg/head/day when grazed on lucerne in Spain (Blanco et al., 2010) and were supplemented with barley grain (1.8 $kg_{DM}$/head/day). Based on the above presented research results, lucerne can be regarded as a high-quality forage that enables excellent livestock productivity when supplemented with mainly energy-rich concentrates. Without supplementation it enables for fair livestock productivity if grazed when young, either as a pure stand pasture or in a mixed stand with perennial grasses.

7.3.1.1.2. Yield

Annual forage DM yields of lucerne vary with variations of soil quality, climatic conditions and applied agronomy. At high elevations and latitudes expected yields are lower. In Anatolia (east of Turkey), at an elevation of 1853 m a.s.l., Coruh and Tan (2008) annually obtained only three cuts of lucerne with an average yield of 4.24 $t_{DM}$/ha during the seven years of field research. At nine locations of Canada, Fairey et al. (2000) achieved about 4 to about 10 $t_{DM}$/ha in two to three annual cuts, depending on the location tested. In warm and temperate climate near Lincoln at the South Island of New Zealand, Palmer and Wynn-Williams (1976) achieved about 15 $t_{DM}$/ha of lucerne yield, with annual precipitation of about 660 mm. In mediteranean climate of Isparta (west Turkey, 1035 m a.s.l.), Albayrak and Türk (2013.) achieved high lucerne yields, significantly greater than cool-season perennial grasses, with more even distribution of annual yield into particulars cuts (Table 15). Although they applied some irrigation in their trial (without a report of the irrigation rate), authors here assume that irrigation was very modest since the tested grasses yielded much less than lucerne.

Table 15. Lucerne and perennial grasses yield in Isparta, western Turkey (Albayrak and Türk, 2013)

| | | Yield ($t_{DM}$/ha) | | | | |
|---|---|---|---|---|---|---|
| Year of experiment | Forage species | 1st cut | 2nd cut | 3rd cut | 4th cut | Total |
| 2009 | Lucerne | 5,10 | 4,20 | 3,10 | 3,70 | 16,10 |
| | Smooth brome | 3,30 | 0,90 | 0,75 | 0,80 | 5,75 |
| | Cocksfoot | 2,80 | 0,70 | 0,50 | 0,55 | 4,55 |
| | Meadow fescue | 2,30 | 0,80 | 0,40 | 0,50 | 4,00 |
| 2010 | Lucerne | 5,70 | 4,10 | 2,80 | 2,20 | 14,80 |
| | Smooth brome | 3,90 | 1,10 | 0,70 | 0,65 | 6,35 |
| | Cocksfoot | 3,00 | 0,80 | 0,60 | 0,40 | 4,80 |
| | Meadow fescue | 3,40 | 1,00 | 0,80 | 0,50 | 5,70 |

Officially reported national average lucerne hay yields in Croatia, from 2010 till the 2014 year, varied from 5.0 to 6.9 t/ha (DZS, 2015) with the greatest yields in the Pannonian region of Croatia (6.3 to 8.5; DZS, 2009), due to the highest quality of soils in the same region. Though, farmers in northeastern Croatia, on high-quality soil, easily achieve higher lucerne hay yields, of about 10 t/ha (Petričević, 2015), whilst on more acidic and heavier soils with somewhat poorer drainage achieve lower yields of about 6 t/ha (Čunko, 2015; Lončarić, 2014). However, the yield potential of lucerne in northeastern Croatia is about double than achievements of practical farmers. For example, Tucak et al. (2012) obtained 20.7 $t_{DM}$/ha in a three-year average for nine lucerne varieties and four breeding populations in a field trial in Osijek (the northeast of

Croatia). Similar results were achieved in much older field trial in Osijek, too: Bošnjak et al. (1988) obtained about 21 t/ha of hay in the average of 25 lucerne varieties in the second and third year of lucerne exploitation, while in the first-year average yield was 11 t/ha, due to the early-spring seeding term. Causes for such a great difference between production potential and achievements of practical farmers lie in utilization practices. In scientific field trials lucerne is utilized in a *cut-and-carry* manner, i.e. lucerne herbage is removed immediately after cutting by hand or after mowing by lightweight mowers. Oppositely, in practical farming, lucerne is utilized mostly for hay or haylage production. For haying lucerne, it has to be mowed (4 to 5 cuts annually), the mowed herbage (swath) has to be tedded, thereafter raked into windrows, baled and transported off the field. Each operation (mowing, tedding, raking, baling and transport) is being performed by a tractor that weighs at least 3.5 tons, plus implement of at least a few hundred kilograms what causes significant soil compaction. The total annual number of machinery passes over a lucerne field is about 25 or more when haying what amplifies the soil compaction problem and consequently detrimentally affects the lucerne's root function. Głąb (2008) has proved in Poland that six annual passes of the light tractor (2056 kg) over lucerne crop diminishes its yield up to 18 % when compared to hand-harvested lucerne with no passes of the tractor. Besides the yield losses due to soil compaction induced by machinery, practical farmers very often lose their first-cut hay due to rain incidence during haying (that is about ¼ to 1/3 of annual yield). A considerable portion of yield is lost due to losses during the hay curing and handling too. In the *cut-and-carry* utilization, losses are minimized to almost zero. Yield advantage of about 100 % in favor of *cut-and-carry* utilization appears attractive and draws to reconsideration of currently prevailing way of utilization and to a search for more yielding alternatives. Grazing may also be an option to increase the utilizable yield of lucerne. Leach (1983) has revealed that the yield of *cut-and-carry* utilized lucerne was similar to the yield of sheep-grazed lucerne (about 11 $t_{DM}$/ha/year) in New Zealand. Moreover, when sheep were rotationally grazed on lucerne in short occupation periods (up to four days), the annual yield was even greater (about 12 $t_{DM}$/ha).

7.3.1.1.3. Agrotechnical measures

Choice of soil and crop rotation

For high yields and a long exploitation period, lucerne should be grown on deep, loose and fertile soils with favorable water regimes, i.e. good drainage (Stjepanović et al, 2009). It can thrive well even on light soils because of its deep rooting, which enables it to reach the deep water and nutrients reserves. According to the research conducted on a sandy loam in New Zealand (Evans, 1978), lucerne takes the water from at least 210 cm depth of soil. Lucerne cannot thrive in water-logging conditions. Regarding the pH reaction of soil, lucerne requires about neutral ones (in the range of $pH_{(H_2O)}$ from 6.2 to 7.5). Research conducted at Northeastern Croatia (Tucak et al., 2007) revealed that lucerne persistence was shortened to only three years on acidic soil in Petrijevci ($pHH_2O$ 4,72) instead of at least four to five years on neutral soil in Osijek. The yield was also reduced by about 1/3 in Petrijevci when compared to Osijek location.

Lucerne has to be grown in crop rotation to avoid yield decrease, excessive pests invasion, disease spread and loss of stand density. The field or plot where lucerne was previously grown has to be rested from lucerne for a few years (Sjepanović et al., 2009). Thinned old lucerne stand cannot be renewed by residing the lucerne because of autotoxic secretions of old lucerne plants (Volenec and Johnson, 2004). A better option for stand improvement is to seed-in some grasses. Lucerne is regarded as an excellent forecrop to crops which demand much nitrogen, like maize.

Soil fertilization

Lucerne uptakes large quantities of mineral nutrients every year of exploitation. The yield of 10 $t_{DM}$/ha removes about 320 kg/ha of N, 90 kg/ha of $P_2O_5$, 280 kg/ha of $K_2O$, 100 kg/ha of Ca and 20 kg/ha of Mg.

Thanks to its root symbiosis with *Sinorhizobium meliloti*, lucerne is largely independent of mineral N fertilization for the achievement of high forage yields. On less adequate soils (acidic, compact, less fertile) little N dressing can give some yield advantage. Soils in areas where lucerne is traditionally grown, naturally contain the aforementioned bacterial root symbiont so the artificial inoculation of lucerne seeds is rarely required. Despite the considerable uptake and removal of P and K, it is not economical to fertilize the lucerne with doses equal to the removal since lucerne uptakes P and K from the deep soil reserves. In most cases there would be probably enough to fertilize with just a third of the removal. Manuring the field before the primary soil tillage for lucerne is probably much more important than the application of mineral fertilizers. Farmyard manure (FYM), besides the content of N, P, K, Ca and Mg, brings the high-quality organic matter into the soil, stimulates biological activity in the soil, improves the soil structure, and even neutralizes the soil acidity (Min et al., 2003; Hakl et al., 2016), what altogether favors the lucerne growth and yield. Average FYM dose of 35 t/ha brings about 175 kg/ha of N, 90 kg/ha of $P_2O_5$, 230 kg/ha of $K_2O$, 210 kg/ha of CaO and 60 kg/ha of MgO, plus micronutrients and plant-growth stimulators. Manuring can be done after the last seasonal cut is removed and before the onset of spring growth too, but with lesser dosages. Soil acidity is usually being corrected by liming. Liming the acidic soil in Drakčići ($pH_{KCl}$ 4.8 and mobile aluminum 16.2 mg/100g of soil) with 2.5 t/ha of lime (by plowing-under) raised the lucerne yield in the first year from 1 to 12.6 $t_{DM}$/ha, and in the second one from 0 to 4.4 $t_{DM}$/ha (Milić et al., 2014). Liming with 12 t/ha of limestone on acid clayey soils in the USA (Wolf et al., 1994) extended the lucerne exploitation period to five years, while the smaller dose (3.1 t/ha of limestone) enabled the exploitation for only two years because of loss of lucerne stand density. In the same research, lucerne persisted longer when limestone was left on the soil surface than when incorporated into the soil (plowed-under). They have revealed that liming can be efficient even in no-till agronomy, that halved limestone doses can be efficient, and that it is more important to correct the acidity in the top 8 cm of soil than in the whole plowing depth. Oppositely to the presented findings, Popović et al. (2009) didn't observe any lucerne yield improvement upon liming the acidic soil in Pavlovac ($pH_{KCl}$ 4.6 and $pH_{H_2O}$ 5.61; Bjelovar-Bilogora County, mid-continental Croatia) with 10 t/ha of dolomite (56% CaO + 40% MgO).

Soil tillage and seedbed preparation

Although the lucerne can successfully be established and give high yields with no-till agronomy (about 15 $t_{DM}$/ha; Singer et al., 2003; New Jersey, USA), some authors recommend the deep primary soil tillage (40 to 45 cm) before the lucerne establishment (Stjepanović et al., 2009). The purpose of deep primary tillage is, according to them; to break the plow pan and enable the deeper rooting. However, Leto et al. (2006) have achieved good lucerne yields (about 12 $t_{DM}$/ha) on hilly soil of Medvednica Mountain (660 m a.s.l., North-western Croatia) upon plowing to a depth of only 20 cm. The choice of primary tillage depth has to be adjusted to the quality of soil: well-structured soils can be tilled shallower, whilst soils with reachable compacted layer should be tilled deeper. Primary tillage should level the soil surface if there were present dead-furrows. When primary tillage is done in summer, for the end-summer seeding term the soil mostly has to be disked to crash the clods before seedbed preparation. Sometimes rotary harrow can be needed for sufficient crushing. In temperate climatic zones, winter freezing often makes the finely structured soil surface which is easy to prepare for seeding in just a few passes with tine harrow (for the early-spring seeding term). Seedbed preparation has to make a shallow, fine-structured and slightly compacted seeding layer (at depth of about 2-3 cm), covered with a loose cover, since the lucerne seed is very small (weighs only about 2 g/1000 seeds) and the seedling is very thin.

Seeding

For high lucerne yields, there is a required stand density between 350 and 400 plants per $m^2$ in the first year, 100 to 180 plants per $m^2$ in the second year, 80 to 100 plants per $m^2$ in the third year and 40 to 60 plants per $m^2$ in the fourth year (Stjepanović et al., 2009). Lucerne crop normally exhibits a self-thinning during its lifespan (Palmer and Wynn-Williams, 1976) and the loss of stand density is naturally being compensated with increasing branching of survived plants. Lucerne is usually being seeded with seeding machines for small-seeded cereals (e.g. for wheat) with an inter-row distance of about 12.5 cm. To establish lucerne crop, in ideal conditions there would be required about 10 kg/ha of lucerne seed to achieve about 400 plants per $m^2$ (if we assume the germination rate is between 80 and 85 %). However, we recommend the seeding rate of about 15 kg/ha to compensate for possible losses due to insect pests attack and for the unperfect seeding technique (some seeds can be placed too deep and some too shallow for quick and reliable emergence). Surprisingly, the research of Palmer and Wynn-Williams (1976) in New Zealand has shown that a highly productive lucerne crop (about 15 $t_{DM}$/ha) can be established with only about 3 kg/ha of lucerne seeds. This was probably because in-row seeding places the lucerne plants too near to each other, and probably due to the absence of stand loss that can occur due to pests attack. Regarding the seeding depth, we recommend seeding between 1 and 2 cm deep. It is beneficial to seed the lucerne with a machine seeder equipped with a pressing wheel that compacts the soil after the seed was placed, to improve the contact between seeds and soil. Seeding machines should have an adequate seed handling mechanism, capable to handle and finely tune the dosage of small lucerne seeds. It would be probably wise not to forget that lucerne was historically seeded by hands. Seeds were taken between fingers and spread by throwing. Upon the spread of seeds, they were shallowly tilled into the soil by light tine harrows. Considering the seeding term, in temperate climates like Croatian, there are recommended two seeding terms: late summer and early spring. The late summer term, for example in continental Croatia, is traditionally from mid-August till the first decade of September. Lucerne here has to be seeded timely to emerge early enough and develop the required hardiness for overwintering. This seeding term is much appreciated because lucerne grows pretty clean from weeds, and after overwintering, lucerne starts its spring growth well rooted, thus enabling high yields even in the first year of utilization. However, soil preparation can often be challenging because dry soil in summer is hard to plow and prepare for seeding. Considering the early spring seeding term, there appears an advantage for seedbed preparation, which is much easier, because of fine-structured soil due to winter freezing of plowed soil. However, lucerne starts its spring growth as a seed, with much delay when compared to overwintered lucerne. Therefore, the farmers can achieve a smaller number of cuts and considerably lower yield in the first year of lucerne utilization. Weeds infestation is usually much greater here in the first year. Very often weeds can comprise half of the yield of the first cut of the lucerne crop.

Choice of cultivar

Before seeding, farmers have to choose a proper variety of lucerne. Lucerne varieties distinguish among themselves according to their dormancy rating, in the range from 1 to 11. Low dormancy ratings (about 2) indicate good winterhardiness and early onset of dormancy (during the autumn), while the high dormancy ratings (about 9) indicate poor winterhardiness, poor winter dormancy and visible growth during winter which is appreciated in warm climates. The majority of lucerne cultivars on the seed market are *erectum*-type, bred for cutting of mowing, while there are few cultivars of *prostrate*-type, resistant to grazing. Locally bred or tested cultivars can probably be the best suited for local conditions.

Nursing

Rolling after seeding improves soil-to-seed contact and enhances the emergence. In the case of crust being formed upon heavier rainfall after seeding and before the emergence, the break of crust can be done with special rollers. Tine-harrowing of older lucerne stands can help in the aeration of the top layer of the soil and pulling-out the weeds. Tine harrowing can be done after each cut and before the spring growth, but always when soil is dry enough to avoid the soil compaction.

## Crop protection

Seeding the pure lucerne seeds is obligatory to avoid soil infestation with weed seeds. Among the weeds spread by seed, especially dangerous is dodder (*Cuscuta* sp.), the parasite plant. Upon the lucerne crop establishment, weeds can be controlled mechanically (by tine-harrowing), culturally (by timely mowing) and chemically (by herbicide application).

Field rodents (voles – *Microtus arvalis*, mice – *Apodemus agrarius* and hamster – *Cricetus cricetus*) can make much damage to lucerne crops by grazing the lucerne herbage and biting the roots of lucerne. Conventional field rodents' control is done by poisoned baits that are usually being placed into holes of field rodents. Traditionally, peasants were placing T-standpoints for predatory birds into lucerne crops to improve their predatory activity in decreasing the field rodents' populations. Traditional rural landscape with small forests was more appropriate for inhabitation of natural enemies of crop pests than the modern uniform arable landscape, so the restoration of small forests could probably improve the biological pest control.

Among the insect pests, most important are lucerne beetle (*Phytodecta fornicata* Brugg.) and lucerne ladybird (*Subcoccinella vigintiquatourpunctata* L.). Both of them feed on lucerne foliage, while the first one can make more serious damages. The simplest protection measures against their attack are crop rotation, placement of new lucerne crops far from the old ones, and mowing lucerne before the sexual maturation of adult insects.

Considering the fungal diseases of lucerne, the best measures to avoid them are the choice of proper soil, crop rotation, and timely mowing or grazing.

## Utilization by cutting (mowing)

Mowing lucerne for the production of harvested forages (hay, haylage, silage) is the most important way of utilization worldwide. The developmental phase of lucerne at the time of mowing strongly affects the quality of the produced forage and the productivity of lucerne. Many practitioners agree that the optimum relation between yield and quality is being achieved when lucerne is cut in the phase of budding (visible flower buds). Earlier mowing can provide for better forage quality (digestibility and CP content) but usually at some expense of annual yield. In the case of cold springs, budding can be delayed, and then the first cut can be taken when secondary stem buds appear to form the base of the lucerne plants. Optimum periods of undisturbed growth between two defoliations is usually about 30 days, except for the last autumn growth, which should be about 50 days (in Croatian conditions for example). In continental Croatian conditions, the rhythm of mowing is usually about the following dates: 1st of May, 1st of June, 1st of July, 1st of August and 20th of September (totally five cuts per season). The yields of the first two cuts are usually the highest, and the subsequent ones are coming lower and lower. Cutting height should be about 5 cm above soil level. Mowed herbage can be taken from the field for direct feeding, or can be dried on the soil to produce the lucerne hay, haylage, or silage. Subsequent growths are impeded by herbage that lies on the soil, so there is recommended as sooner as possible to remove the hay or mowed herbage.

## Utilization by grazing

Lucerne grazing is considerably spread in Argentina, New Zealand and Australia. Despite the risk of frothy bloat for livestock grazing lucerne, lucerne is attractive for grazing due to its drought resistance and very good summer growth, when the majority of grasses (cool-season grasses) exhibit summer slump. To enable for good yields and stand longevity of lucerne, the rhythm of defoliation should enable for about 30 days of undisturbed regrowth during the vegetation season, although research from New Zealand has shown that it can be even shorter (about 20 days, Berone et al., 2020). They have implied shorter rest periods for lucerne with aim to achieve better digestibility and greater energetic value of grazed lucerne. Their annual yields

were between 7 and 10 $t_{DM}$/ha. In their research, they revealed that it is best to start grazing when lucerne is 35 cm high, and to limit the period of occupation of lucerne paddock to four days.
The risk of bloat on lucerne pasture can be sufficiently decreased by several measures. Lucerne can be grown in the mixed stand with grasses to dissolve the bloat potential, and with herbs, legumes and weeds that contain tannins (birdsfoot trefoil – *Lotus corniculatus* L., sainfoin - *Onobrychis viciifolia* L., docks - *Rumex* sp.). Livestock should enter the lucerne-rich paddock in the afternoon, when nitrates are build-in into plant protein. Livestock should not enter the lucerne-rich paddock when hungry, but only with (at least partially) full rumens. This can be done by removing the livestock from the previous paddock when there remains a considerable residual herbage, and by providing the two-days-before cut lucerne herbage of about a quarter of the new paddock area (so the livestock will first consume the wilted lucerne) or by providing the livestock with high-quality (easily palatable) hay before entering the new lucerne paddock. Grazing of pure lucerne paddock is nowadays routine in New Zealand with neglectable risk of bloat.

Mixes with grasses

Lucerne is rich in protein content but somewhat poorer in energy. Forage grasses can complement lucerne due to their opposite properties – they are richer in energy but somewhat poorer in protein content. Therefore, in stands aimed for grazing, mixtures of lucerne with grasses can provide a better-balanced ratio. The presence of grasses in the grazed stand decreases the risk of bloat too. Considering the hay-cut stands, grasses usually dry faster than pure lucerne, and so do the grass mixes with lucerne too. In Cullen's (1965) experiments in New Zealand, the highest yielding lucerne-grass mixes were with cocksfoot (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea* L.). In his trial grasses did not suppress lucerne because the share of grasses in stands was relatively smaller. In research of Douglas and Kinder (1973) at New Zealand too, pure lucerne had greater yield than its mixes with grasses (cocksfoot, tall fescue, and others).

7.3.1.2. Red clover

According to Shaeffer and Evers (2007), red clover (*Trifolium pretense* L.) is best adapted to climates with modestly cold to warm summers and with a good supply of water. Red clover cannot tolerate drought and heat, as well as lucerne, can. Considering the soil quality, it can tolerate acidity better than lucerne (up to pH 5.5) where it is used as an alternative to lucerne. It also tolerates poorer drainage and lower soil fertility better than lucerne (Undersander et al., 1990). Red clover is cultivated in Canada in the zones where lucerne cannot thrive due to poorer soil drainage (Lafreniere and Drapeau, 2011). Red clover has a lower frothy bloat risk than lucerne when grazed (Hilton, 2008). According to the occupation of arable land in Croatia, red clover is the second perennial legume, after lucerne being the first, and it is cultivated mostly on poorer quality soils and in more humid conditions. Red clover is almost ubiquitous in spontaneous plant communities of perennial grasslands in Croatia. In Croatia it is traditionally called "(djetelina) trećakinja" (three-year clover) because of its utilization period of usually up to three years. Also, there is historically called "(djetelina) kravarica" because it was very appreciated by cattle farmers.

7.3.1.2.1. Feed value

Just like any forage species, the content of nutrients and energetic value of red clover strongly depends on the developmental stage of red clover (Table 16). In comparison with lucerne, red clover has a somewhat greater energetic value and somewhat lower crude protein content, in analogous developmental stages. It has a greater share of bypass protein, and its fibers are more digestible than in lucerne.

Table 16. Red clover feed value (DLG, 1997.)

| Forage | The developmental stage of red clover | DM (%) | CP (% in DM) | CF (% in DM) | NEL (MJ/kg$_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Fresh herbage 1st growth | Before budding | 14 | 22,7 | 15,8 | 6,87 | 74,0 |
| | Budding | 16 | 19,3 | 21,3 | 6,44 | 71,0 |
| | Beginning of bloom | 22 | 16,1 | 26,1 | 5,82 | 65,4 |
| | Mid to end of bloom | 25 | 15,0 | 29,6 | 5,47 | 62,7 |
| | Off bloom | 28 | 14,1 | 33,3 | 5,18 | 59,3 |
| Silage 1st growth | Before budding | 35 | 21,2 | 19,6 | 6,24 | 70,7 |
| | Budding | 35 | 18,2 | 23,4 | 6,03 | 67,3 |
| | Beginning of bloom | 35 | 15,5 | 27,7 | 5,58 | 63,6 |
| | Mid to end of bloom | 35 | 15,0 | 30,9 | 5,32 | 62,6 |
| | Off bloom | 35 | 13,9 | 35,1 | 4,87 | 56,8 |
| Hay 1st growth | Budding | 86 | 15,7 | 25,8 | 5,51 | 63,1 |
| | Beginning of bloom | 86 | 15,5 | 30,0 | 5,25 | 60,2 |
| | Mid to end of bloom | 86 | 13,4 | 33,6 | 5,05 | 59,0 |
| | Off bloom | 86 | 13,5 | 37,6 | 4,31 | 51,2 |
| | * Calculated according to Maynard (1953.) upon crude nutrients content and digestibility DLG-u (1997.) | | | | | |

Research by Broderick et al. (2000) in Madison (Wisconsin, USA) has shown that red clover silage in dairy cows' ratios provides for a similar milk yield as provides lucerne silage. Their cows were fed TMR that comprised 65 % of legume silages (either red clover or lucerne) and 33 % maize grain, on a DM basis.

### 7.3.1.2.2. Yield

Red clover hay yields in Croatia are somewhat lower than lucerne's (about 11 % lower; DZS, 2015). The national average from 2010 to the 2014 year was between 4.1 and 6.8 t/ha. On acid soil (pH$H_2O$ 4.79) near Kraljevo in Serbia, Katić et al. (2006) achieved a red clover hay yield of 11.6 t/ha and lucerne of only 2.2 t/ha, both in the second year of crop utilization. Upon liming with 3 t/ha of lime, red clover hay yield was 13.3 t/ha and lucerne 16.3 t/ha. Their results indicated that red clover tolerates soil acidity much better than lucerne, and that red clover's positive reaction to liming is not so pronounced as lucerne's. In mediteranean climates, lucerne gives higher yields than red clover, as proved in the field trial of Albayrak and Türk (2013) in Turkey. Very high red clover yields were achieved in field trials in Osijek and Zagreb (east and west parts of continental Croatia): 15.8 to 20.1 tDM/ha in the second year of exploitation (Popović et al., 2011).

### 7.3.1.2.3. Agrotechnical measures

Agrotechnical measures for red clover are very similar to ones for lucerne with some particularities. According to Undersander et al. (1990), red clover will positively react to P and K fertilization in cases of lower availability in soil than lucerne will. Red clover's root system is more spread near the soil surface so there is not so important deep positioning of fertilizers. Liming of acidic soils is not so crucial to red clover as to the lucerne. The beneficial effect of manuring is expected as well as for the lucerne. Seeding terms and seeding rate (about 10 to 15 kg/ha of seed) are very similar to lucerne. Besides the conventional seeding, there is the well-known term "frost seeding" at the end of winter, when alternate freezing and thawing of soil enables for intimate seed-to-soil contact of aerialy spread seeds. Red clover can be frost-seeded into the winter wheat crop. It emerges and grows below the canopy of wheat and upon the wheat harvest, it flourishes and gives summer and autumn forage yield. Though, the success of red clover establishment by frost seeding into winter cereals is not guaranteed, and established stands can be thinner than optimal. Considering the choice of cultivar, locally bred and tested cultivars could be best adapted to the local soil and climatic conditions. On the seed market there are prevailing naturally diploid cultivars, but the artificially tetraploid ones are also available. Regarding the defoliation regime, red clover positively reacts to the longer rest periods than lucerne (higher yields at 6-weeks interval than at 4-weeks). For haymaking, it is usually cut at the phase of fool bloom, thus annually providing one cut less than lucerne in the temperate climate of continental Croatia. The persistence of the red clover stand can be extended much longer than three years by enabling the seed ripening and spontaneous self-reseeding. Red clover performs well in pasture systems because it doesn't sharply decrease palatability neither digestibility with senescence, and it can be stockpiled for winter grazing (Kintzell, 2020). Association with perennial grasses speeds up the drying of mowed herbage for hay production and balances the energy-protein ratio.

7.3.1.3. White clover

White clover (Trifolium repens L.) is the most ubiquitous perennial legume in pastures (Abberton and Marshall, 2010). Although it originates from the temperate climatic zone, it is obviously well adapted to the broader area: from the Arctic to subtropics, and up to the elevation of 6000 m a.s.l. (Sareen, 2003). Oppositely to lucerne and red clover, which mainly have erected to the semi-prostrate type of growth, white clover has a creeping growth habit. Its creeping stem (stolon) accumulates assimilates for the regrowth after defoliation and overwintering, and for the vegetative spread of the mother-plant with capability for distant rooting. Its creeping growth makes it very tolerant to continuous grazing. Cultivars of white clover can be classified into small-leafed (low-yielding but very resistant), medium-leafed and large-leafed (Ladino type, high-yielding but with poor persistence). The longevity of white clover in plant communities is very long (medium- and small-leafed ones). According to the authors' observations, spontaneous plant communities beside pathways, field ways, roads, and on channel banks and riverbanks continuously comprise various content of white clover despite the absence of seeding and reseeding. White clover is most visible during summer, after the spring cuts of dominating grasses were mowed. The role of white clover in pasture plant communities is indispensable because it improves the protein content in available herbage, fixes more atmospheric N than it needs, thus making it available to the neighboring grasses, and improves the summer pasture yields, when the majority of cool-season grasses fall into a summer slump. It tolerates soil acidity and temporary water-logging even better than red clover, and tolerates drought and heat better than many cool-season perennial grasses.
The primary usage of white clover is grazing, and rarely for the production of harvested forages (hay, haylage, or silage), unless its purpose is to supply symbiotic nitrogen for accompanied tall and high-yielding grasses.

7.3.1.3.1. Feed value

The high feeding value of white clover (Table 17) is the consequence of its creeping growth habit. Namely, there are being harvested (grazed or mowed) only leaves, inflorescences, and petioles, but not the stems.

Table 17. White clover feed value (DLG, 1997.)

| Forage | Developmental stage | DM (%) | CP (% in DM) | CF (% in DM | NEL (MJ/kg$_{DM}$) | TDN* (% in DM |
|---|---|---|---|---|---|---|
| Fresh herbage, 1st growth | Before bloom | 12 | 25,6 | 14,8 | 7,08 | 75,4 |
| | Bloom | 13 | 22,9 | 18,8 | 6,74 | 72,5 |
| | End of bloom | 14 | 19,6 | 20,9 | 6,14 | 70,0 |
| | * calculated according to Maynard (1953.) and digestibility of comprised nutrients (DLG, 1997.) | | | | | |

7.3.1.3.2. Yield

White clover yields are certainly lesser than yields of its upright relatives lucerne and red clover. To achieve higher yields, it is mainly grown in mixes with perennial grasses. Since white clover is usually grown in mixes with perennial grasses, available data about yields are related mainly to yields of mixes. A mixture of perennial ryegrass and other grasses (about 70 % of soil coverage) with white clover (about 30 % of soil coverage) in the Netherlands yielded about 10.1 $t_{DM}$/ha in a three-year average, with modest fertilization (69 kgN/ha through liquid manure)(Schils et al., 2000a). That was insignificantly less than the yield of intensively fertilized pure grass stand (71 % perennial ryegrass in soil coverage, 275 kgN/ha). During the summer, mixed stand gave more herbage than pure grass stand. The trial was conducted in a humid climate with average annual precipitation of 785 mm and an average temperature of 9.1°C. In Great Britain, mixed perennial ryegrass – white clover pastures yield about 10 $t_{DM}$/ha (Benever, 2015), and there is a targeted share of white clover in DM yield about 30 %. In subtropical conditions of Turkish county Trakya (624 mm/year, 14.5°C avg.temp.), the yield of tall fescue – white clover mix was about 7 $t_{DM}$/ha (Tekeli and Ates, 2005) with white clover share in DM yield of only 23 %, and without nitrogen fertilization. Pure tall fescue in their trial yielded only about 5 $t_{DM}$/ha because of the absence of white clover as an important nitrogen contributor.

7.3.1.3.3. Agrotechnical measures for white clover production

Agrotechnical measures for the establishment of white clover are very similar to the ones recommended for lucerne and red clover. However, there are some particularities.
According to Schaeffer and Evans (2007), white clover tolerates soil acidity, moist soil, coldness, frequent defoliation, and even salinity, but poorly tolerates drought and alkaline soils. However, according to the authors' observations, white clover in spontaneous plant communities of continental Croatia successfully survives dry summer conditions, even on well-drained soils, but with delayed growth until the onset of more favorable conditions. Moreover, in the average summer conditions of the semiarid east continental part of Croatia, white clover continues to grow during summer, thus compensating for the lack of summer growth of cool-season grasses.
Tekeli and Ates (2005) achieved a white clover share of 23 % (on DM basis) in total grass-clover mix yield with tall fescue with white clover partial seeding rate of only 2.5 kg/ha of white clover seeds. That was 25 % from the pure stand seeding rate of 10 kg/ha. The partial seeding norm of tall fescue was 15 kg/ha (75 % from the pure stand seeding norm). Benever (2015) recommends seeding white clover with 1 to 4 kg/ha of seeds in mixes with perennial ryegrass. However, Schils et al. (2000) have achieved a share of white clover in soil coverage of 30 % with its partial seeding norm of 5 kg/ha of white clover seeds. The partial seeding rate for perennial ryegrass was 20 kg/ha. Seeds of white clover are smaller than of lucerne and red clover (only about 0.6 g/1000 seeds). Rising the share of white clover in pastures can be done by seeding-in with no-till seeding machines or by the simple aerial spreading of white clover seed over the existing pasture stand. It is useful to graze the existing pasture to the very low residual herbage height (just a few cm) before spreading the white clover seeds. After spreading the seeds, livestock trampling can enhance the soil-to-seed contact for quicker emergence of white clover. Intensive grazing upon white clover emergence can help lessen the suppression of young white clover plants by old grasses.
Grasslands and pastures that contain 9 to 20 % of white clover can be very productive without additional nitrogen fertilization (Ledgard et al., 2001). Mineral nitrogen fertilization of pastures that comprise white clover decreases the white clover content. It consequently makes the pasture more dependent on nitrogen fertilization. Moreover, pastures with decreased clover content produce less herbage during summer. Organic manures, like farmyard manure, are a much better option to fertilize grasslands and pastures because they rarely suppress the legumes in them. Farmyard manure also brings the P, K, Ca, Mg and micronutrients in a well-balanced amounts suited to the needs of plant communities.

To prevent the frothy bloat in ruminants grazing clover-rich pastures, farmers should not let the hungry livestock in, and livestock should be gradually adapted to a high-clover diet. A small amount of hay before grazing clover-rich pasture is also beneficial. There can help a small amount of toasted soybean before grazing too because the soybean contains much fat with unsaturated fatty acids (Schils et al., 2000b).

7.3.1.4. Birdsfoot trefoil

According to Undersander et al. (1993), birdsfoot trefoil (*Lotus corniculatus* L.) is a perennial legume with a lifespan between two and several years. However, established birdsfoot trefoil stands persist much longer due to self-reseeding. In the USA it is primarily used in pastures. For hay production, it is mainly used on poorly drained and acid soils, where lucerne cannot thrive. Although it tolerates poorly drained soils, it will not thrive on areas waterlogged during summer. Its root is shallower than lucerne's and therefore is less resistant to drought. The main advantages of birdsfoot trefoil are: it does not induce bloat in grazing livestock, it has excellent tolerance to grazing (prostratum types) and it is persistent due to self-reseeding. According to Waghorn et al. (1998) it is suited for low fertility soils. It contains condensed tannins that provide for bloat prevention, a decrease of nematode parasites in livestock, and better performance of livestock when compared to pure grasses or pure lucerne.

7.3.1.4.1. Feed value

Ayal (2001) in Uruguay tested birdsfoot trefoil's crude protein content and in-vitro organic matter digestibility which is proportional to the energetic value of feed (Table 18). Its chemical traits are very similar to lucerne's and red clover's.

Table 18. Content of crude protein and digestible organic matter in birdsfoot trefoil in Uruguay (Ayal, 2001)

| Developmental stage | SB (% in DM) | Content of *in-vitro* digestible organic matter (% in DM) |
|---|---|---|
| Vegetative | 18,8 to 24,4 | 62,6 to 67,0 |
| 50 % bloom | 15,6 to 18,1 | 61,9 to 68,3 |
| Off bloom | 11,8 to 14,4 | 49,5 to 56,2 |

Feeding trial in Missouri (the USA, Wen et el., 2002) has shown that steers grazed pure birdsfoot trefoil had greater average daily liveweight gain (1.29 to 1.53 kg/head/day) than ones grazed mix of birdsfoot trefoil with tall fescue (0.93 kg/head/day) and pure tall fescue (0.73 kg/head/day). They used a tall fescue variety Phyter free from endophyte.

7.3.1.4.2. Yield

In the field trials in Great Britain on drained loamy and stony soil (Marley et al., 2006) 13 birdsfoot trefoil varieties gave between 1.5 and 7 $t_{DM}$/ha in the first year of exploitation, and between 2.3 and 6.7 $t_{DM}$/ha in the second year. Yield varied due to variety. A very similar range of yields was achieved by Ayal (2001) in Uruguay with several tested varieties. In mid of Italy, on slightly alkaline loamy calcareous soil poor in phosphorus, birdsfoot trefoil out yielded lucerne (5.3 vs. 4.2 $t_{DM}$/ha), while in northern Italy, on pH-neutral soil, lucerne out yielded birdsfoot trefoil (7.4 vs. 2.3 $t_{DM}$/ha; Pecetti et al., 2008a). In the authors' observations of birdsfoot trefoil performance in grazed complex grass-clover mixes near Zdenci (continental Croatia, poor fertility and acidic soil, unpublished data), birdsfoot trefoil growth was inferior to red clover in areas with better soil quality. In areas with poorer soil quality, red clover disappeared after the first year of exploitation, and birdsfoot trefoil partly compensated for the lack of summer herbage growth there. Seeding birdsfoot trefoil in tall fescue grasslands in Missouri (USA) can save much nitrogen if legume content is about 30 % in DM yield, and can provide for greater steers ADGs when compared to pure tall fescue stands (Wen et al., 2002).

7.3.1.4.3. Agrotechnical measures for birdsfoot trefoil

Recommended agrotechnical measures are similar to ones for lucerne and red clover. However, it is rarely grown in a pure stand because it is low-yielding forage, and association with grasses provides for much greater forage yields. Less competitive grasses (cocksfoot and cat's tail) allow for the greater persistence of birdsfoot trefoil than dominating grasses (smooth brome, reed canary grass and tall fescue). For the persistence of birdsfoot trefoil in mixes with dominating grasses it is useful to graze the pasture to the low residual herbage mass to suppress the dominating grasses. Pure stands can be achieved with a seeding rate of about 9 kg/ha (Undersander et al., 1993). However, a somewhat greater seeding norm would probably contribute to a more reliable establishment of a dense and productive stand of birdsfoot trefoil. The choice of cultivar should be appropriate. It is best to test the available varieties before seeding a huge area with birdsfoot trefoil. *Prostratum* types are more suitable for grazing, while *erectum* types would be adequate both for mowing and for grazing. Since the birdsfoot trefoil tolerates low fertility soils, authors do not recommend mineral fertilization, but the only application of farmyard manure for birdsfoot trefoil. The optimum rest period between two defoliations for birdsfoot trefoil is about 30 days, and optimum residual height is about 5 cm from the soil level. The last regrowth before winter should be somewhat longer, about 40 days. A residual height of about 7.5 cm can provide for some self-reseeding.

7.3.1.5. Sainfoin (esparsette)

Sainfoin (*Onobrychis viciifolia* Scop.) is an almost forgotten perennial forage legume, which had a long history of cultivation in Europe, at least from antique times. A few centuries ago, its cultivation was spread on calcareous and well-drained soils, but its area gradually decreased until nowadays. Reasons for neglecting this legume are poorer stand persistence when compared to lucerne, lower yield than lucerne's, poorer regrowth after the first cut is taken, abandoning of farming in mountainous areas, the introduction of high-yielding perennial ryegrass cultivars, disappear of working horses (sainfoin was an important forage for working horses) and availability of cheap mineral nitrogen which diminished the importance of legumes. According to Smith (2006), sainfoin is an excellent forage legume with a high voluntary intake in cattle, sheep, and horses. Its comparative advantages are better utilization of plant protein than from lucerne or soybean, better energetic value than lucerne's, and anthelminthic (antiparasitic) effects, due to the content of condensed tannins. Sainfoin means healthy hay in French. It also prevents the bloat in pastured ruminants.

7.3.1.5.1. Feed value

Crude nutrients content and calculated energy of sainfoin are similar to other perennial legumes when compared in analogous developmental stages (Table 19).

Table 19. Feed value of sainfoin's fresh herbage (DLG, 1997.)

| Developmental stage | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) |
|---|---|---|---|---|
| Prior to budding | 16 | 21,7 | 16,7 | 7,24 |
| Budding | 19 | 20,8 | 21,5 | 6,59 |
| Begin of bloom | 23 | 17,1 | 26,7 | 5,93 |
| Mid to end of bloom | 21 | 17,4 | 31,1 | 5,33 |

Feeding ruminants with sainfoin hay before grazing legume-rich pastures could probably help a lot in decreasing the risk of frothy bloat.

7.3.1.5.2. Yield

Research conducted in Oregon (USA) has shown that sainfoin gives forage yield about half of lucerne's (Peel et al., 2004). In the hilly area of southern Italy (De Falco et al., 2000) sainfoin variety Fakir gave 10 $t_{DM}$/ha when used by cutting whilst only 5.5 $t_{DM}$/ha when grazed was simulated (defoliation when plants were 30 cm high). Ecotype Firenzoula gave only 3.8 $t_{DM}$/ha when used in the cutting regime. In the cutting regime of defoliation, the first growth contributed the great majority of seasonal yield. In Great Britain, sainfoin can give about 10 $t_{DM}$/ha, except in the first year upon spring seeding, when yield can be much lower, about 2 $t_{DM}$/ha (Liu, 2006).

7.3.1.5.3. Agrotechnical measures for sainfoin

Sainfoin is adapted to well-drained calcareous soils with pH 6 or greater. It tolerates droughty conditions, but not waterlogging. Seeds can be seeded when covered with their single-seeded pod what helps the quicker emergence. Seeding depth is traditional about 1.5 cm, and the targeted stand is between 70 and 150 plants per $m^2$. The seeding rate is about 100 kg/ha when seeds are in their pods and about 45 kg/ha of shelled seeds. For legume-grass mixes, less aggressive grasses (meadow fescue, cat's tail, and cocksfoot) are a better option for longer persistence of sainfoin. In complex mixes, birdsfoot trefoil will less suppress the sainfoin than other legumes. In the cutting regime, the first cut should be taken from beginning to the mid of bloom. Stand persistence of sainfoin is probably limited to three years, but for more reliable information it should be tested in local soil, climatic, and utilization conditions.

7.4. Perennial grasses

Perennial grasses are the most ubiquitous and abundant plant species in grassland plant communities. There are hundreds of grass species in grasslands worldwide, but only a little more than a dozen are present at the seed market. Marketed grasses are a long time ago recognized for their yield, quality, and ease of seed production. Besides for the renovation of perennial grasslands, they are very often seeded on arable land to produce high-quality hay and/or pasture. Perennial grasses, especially the cool-season ones are appreciated for their quality in herbivore nutrition, for they are being dried more quickly than legumes during hay production, for tolerance to grazing, and adaptability to lower quality soils. We distinguish two groups of perennial grasses: the cool-season ones and warm-season ones. The first ones employ the $C_3$-type of photosynthesis, while the second ones use $C_4$-type of photosynthesis. Cool-season grasses give the majority of their growth during spring, whilst the warm-season grasses have their peak of growth at beginning of summer.

7.4.1. Cool-season perennial grasses

In temperate climates, cool-season grasses are more important than warm-season ones. They are appreciated very much for their fine stems and leaves, very good palatability, digestibility, and protein content, better than in warm-season grasses. Their history of cultivation and seed production is much longer than that of warm-season grasses.

7.4.1.1. Perennial ryegrass

Perennial ryegrass is probably the most spread grass on seeded pastures. It owes its spread to its exceptional forage quality (palatability, digestibility and protein content), to its high potential forage yield, and to tolerance to grazing. Its quality comes from the fact that it is low (short) stature grass (up to 60 cm tall in flowering) with a high share of leaves and a low share of stems in total herbage mass. Moreover, it contains a considerable level of sugars, making it even more attractive to herbivores. Its forage quality does not fall rapidly after flowering like in other grasses. Perennial ryegrass stands persist for up to 10 years when properly grazed while the mowing utilization regime shortens its longevity to three to five years. Therefore, it is primarily used for grazing, and rarely for cut-only utilization. Besides many favorable traits, it is not ideal grass – it is susceptible to water stress, especially to drought. In complex long-term grass-clover mixes it is distinguished for its quick development: unlike other perennial grasses, it achieves its full productivity early, in the first year of utilization (if seeded in the late-summer term of the previous year).

7.4.1.1.1. Forage quality

Its exceptional forage quality is reflected in high crude protein until flowering and high energy content until the end of flowering (Table 20). The particularity of perennial ryegrass is its high sugar content also (10 to 16 % in DM of fresh herbage).

Table 20. Fed value of perennial ryegrass (DLG, 1997.)

| Forage | Developmental stage | DM (%) | CP (% in DM | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Fresh forage, 1st spring growth | Stem elongation | 16 | 24 | 18 | 7,1 | 77 |
| | Ear emergence | 17 | 20 | 20 | 7,1 | 78 |
| | Full earing | 18 | 19 | 22 | 6,8 | 75 |
| | Begin of flowering | 21 | 16 | 26 | 6,4 | 71 |
| | Mid to end of flowering | 23 | 14 | 30 | 6,1 | 70 |
| | After flowering | 28 | 12 | 35 | 5,4 | 63 |
| Silage, 1st spring growth | Ear emergence | 35 | 18 | 21 | 6,9 | 76 |
| | Full earing | 35 | 16 | 24 | 6,3 | 71 |
| | Begin of flowering | 35 | 15 | 27 | 5,9 | 68 |
| | Mid to end of flowering | 35 | 14 | 31 | 5,7 | 67 |
| | After flowering | 35 | 11 | 35 | 5,1 | 58 |
| Hay, 1st spring growth | Ear emergence | 86 | 15 | 23 | 6,5 | 73 |
| | Full earing | 86 | 13 | 27 | 6,1 | 69 |
| | Begin of flowering | 86 | 13 | 30 | 5,7 | 65 |
| | Mid to end of flowering | 86 | 12 | 36 | 4,9 | 60 |
| | After flowering | 86 | 10 | 38 | 4,6 | 59 |
| | * Calculated according to Maynard (1953.) and digestibilities according to DLG (1997.) | | | | | |

Holstein cows grazed either perennial ryegrass or its mix with white clover in France produced milk yield of about 20 kg/cow/day and consumed 13.0 to 16.6 $kg_{DM}$/cow/day of pasture with supplementation of only 300 g/cow/day of pelleted concentrate (Ribeiro Filho et al., 2005.). Greater milk yield, about 30 kg/cow/day, without any supplementation, was achieved in Holstein cows grazing perennial ryegrass – white clover pasture in Pennsylvania (USA; Kolver and Muller, 1998), probably due to the stage of their lactation (peak lactation at about 60th day in milk). Cows consumed 19 $kg_{DM}$/cow/day of pasture, what was 3.39 % of their body weight. In Ireland, Holstein cows milked about 20 kg/cow/day at beginning of lactation on perennial

ryegrass pasture without supplementation (O'Neill et aal l., 2011.). Steers (initial bodyweight 460 kg/head) and heifers (initial bodyweight 406 kg/head) grazed on perennial ryegrass in Great Britain (Steen et al., 2003) had a fair average daily gain of 1.1 kg/head/day and 0.97 kg/head/day, respectively.
Researchers in New Zealand found a certain adverse effects of *Neotyphodium lolii* (Latch) symbiotic fungi in perennial ryegrass to the grazed livestock, but authors could not find any similar reports from neither Europe nor the USA.

7.4.1.1.2. Forage yield

Forage yields vary substantially in Great Britain, in the range from 6.5 $t_{DM}$/ha to 15.0 $t_{DM}$/ha, mainly due to effects of different locations and variation in rainfall during vegetation (Morrison et al. 1980). In New Zealand perennial ryegrass grows even during winter, and annual yield is usually between 10 and 14 $t_{DM}$/ha (Easton et al., 2001). Annual yields of (rich N-fertilized) perennial ryegrass in the Netherlands are usually between 10 and 13 $t_{DM}$/ha (Schils et al., 1999), while its mixes with white clover yield between 9.5 and 15.6 $t_{DM}$/ha. On Medvednica mountain near Zagreb (Leto et al., 2006) perennial ryegrass yielded between 9.1 and 13.8 tDM/ha. In the drier climate of Serbia, perennial ryegrass gave lower yields, between 3.2 and 8.6 $t_{DM}$/ha (Tomić et al., 2007). Italian ryegrass out-yielded perennial ryegrass there with annual yields between 5.8 and 9.4 $t_{DM}$/ha.

7.4.1.1.3. Agrotechnical measures for perennial ryegrass production

Perennial ryegrass thrives well on moderately moist and medium-heavy, to heavy but not compacted soils (Stjepanović et al., 2008). For high yields it requires fertile soils. Considering the soil pH reaction, the optimum range is from 5.5 to 6.5, but it tolerates a wide range from 5.1 to 8.4. Perennial ryegrass may suffer from water shortage on light soils. Poorly drained soils are not suitable for high yields and long persistence of perennial ryegrass.
The annual yield of 10 $t_{DM}$/ha of high quality forage removes about 300 kg/ha of N, 70 kg/ha of $P_2O_5$ and 250 kg/ha of $K_2O$. Nitrogen fertilization is limited by the Nitrate directive to 170 kg/ha of N in Croatia, although, it was historically fertilized with about 250 kg/ha of N in the Netherlands. According to Hannaway et al. (1999), the highest economic nitrogen fertilization for perennial ryegrass is 180 kg/ha of pure mineral nitrogen. However, an association of perennial ryegrass with white clover (with about 25 % soil coverage) in the Netherlands provides forage yields comparable to rich N-fertilized pure stands of perennial ryegrass (Schils et al., 1999). Excessive mineral N fertilization raises the perennial ryegrass yield but increases the urea content in milk as well, and lowers the milk solids production (Ordonez et al., 2004). Excessive K-fertilization lowers the Mg uptake in ryegrass and therefore it can induce milk fever in dairy cows. Farmyard manure is probably the more economical and reasonable source of N, P and K for perennial ryegrass than mineral fertilizers.
Plowing is not crucial for perennial ryegrass establishment and productivity, but in the case of farmyard manure application, plowing can help to incorporate it into the soil. It can be successfully established by no-till technology. Seeding should be shallow, in soil depth of 1 to 2 cm, and can be even shallower. Rolling after seeding can speed-up the emergence in dry conditions. Perennial ryegrass can be frost-seeded in the thinned existing sod. Recommended seeding terms are similar to the lucerne’s (late-summer term and early-spring term). Spring-seeded ryegrass is much less productive in the first year of utilization than late-summer seeded one. Available cultivars can be classified into early, medium and late ones, regarding the onset of flowering. Late cultivars have a longer vegetative phase, when there is a better quality of forage, while the early cultivars start their spring growth somewhat faster and give higher initial growth. It is useful to have a mix of early, medium and late cultivars in the pasture to extend the period of optimal forage offer. Traditional diploid cultivars are probably more persistent, have good sward density and better tolerance to

stress conditions, whilst new tetraploid cultivars can be somewhat taller and higher yielding. The seeding rate of perennial ryegrass seeds for pure stand establishment is between 25 and 30 kg/ha.

Perennial ryegrass should be grazed low and frequently because it recovers quickly. Herbage cannot be stockpiled because older leaves yellow (die) quickly. For the highest quality herbage, grazing should start at a grass height of 15 cm, and stop at a height of 5 cm. The optimal initial herbage mass to start grazing is about 3 $t_{DM}$/ha, and the spring residual is about 1.5 $t_{DM}$/ha. Summer residual should be somewhat greater, about 1.6 $t_{DM}$/ha. First spring growth, if intended for haying, is best to mow at the ear emergence stage.

#### 7.4.1.2. Italian ryegrass

Italian ryegrass (*Lolium italicum* A.Br. synonym: *Lolium multiflorum* Lam) is medium tall (about 80 cm in height in flowering), high-yielding perennial grass, mainly utilized by cutting (mowing) for hay, haylage, and silage production. However, it is often a component of grass-clover mixes aimed for grazing, mainly because it raises the first-year yield of the long-term mixes. Namely, Italian ryegrass reaches its maximum productivity very quickly, already in the first year of exploitation (if seeded in the late-summer term of the previous year), while many other perennial grasses give their full productivity later, from the second year of exploitation and onward. It usually disappears after the second year of exploitation because its lifespan is about two years (it is a short-living perennial grass). It is a good option for a quick renovation of perennial pastures because it gives its full productivity very quickly. In warm climates, summer is usually critical for survival because it dies in the case of extreme heat and drought. In warm climates, it is popular for winter grazing. In regions with sufficient rainfall during summer, it grows even during summer, when the majority of cool-season grasses fall into summer dormancy.

Considering the requirements for soil quality, water, and environment temperatures, it is very similar to perennial ryegrass. For overwintering in colder climates, it requires a snow cover.

Westerwolth ryegrass is a close relative of Italian ryegrass that greatly resembles it. It is an annual grass with even quicker development.

##### 7.4.1.2.1. Feed value

Italian ryegrass has appreciable quality regarding the protein and energy content (Table 21), though somewhat lower than perennial ryegrass, because of the greater share of stems and lower share of leaves in the harvested herbage.

Table 21. Feed value of Italian ryegrass (DLG, 1997.)

| Forage | Developmental stage | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% u ST-u) |
|---|---|---|---|---|---|---|
| Fresh herbage, 1st spring growth | Stem elongation | 16 | 21 | 17 | 7,3 | 78,2 |
| | Ear emergence | 17 | 18 | 20 | 6,8 | 74,6 |
| | Full earing | 18 | 17 | 22 | 6,4 | 71,1 |
| | Begin of flowering | 21 | 15 | 26 | 6,1 | 68,9 |
| | Mid to end of flowering | 25 | 14 | 30 | 5,8 | 65,7 |
| | After flowering | 28 | 12 | 33 | 4,5 | 54,1 |
| Silage, 1st spring growth | Ear emergence | 35 | 15 | 21 | 6,7 | 73,2 |
| | Full earing | 35 | 14 | 24 | 6,6 | 73,1 |
| | Begin of flowering | 35 | 13 | 28 | 6,0 | 67,7 |
| | Mid to end of flowering | 35 | 13 | 31 | 5,0 | 58,5 |
| | After flowering | 35 | 11 | 35 | 4,5 | 54,4 |
| Hay, 1st spring growth | Ear emergence | 86 | 17 | 23 | 6,5 | 71,5 |
| | Full earing | 86 | 15 | 27 | 6,1 | 67,2 |
| | Begin of flowering | 86 | 12 | 30 | 5,7 | 61,2 |
| | Mid to end of flowering | 86 | 9 | 36 | 4,9 | 58,0 |
| | * Calculated according to Maynard (1953.) and digestibility according to DLG (1997.) | | | | | |

Miguel et al. (2012) grazed Holstein cows on Italian ryegrass pasture in Brasil. Cows were about the 114th day in milk and yielded about 20 kg/cow/day of milk. Greater milk yields were achieved when grazed lower herbage than higher one (because of a greater share of live green leaves in shorter herbage, and greater share of dead yellow leaves in taller herbage). In addition, greater milk yields were achieved during the spring growth than during the summer or autumn ones. Cows were not supplemented with concentrates. In Ireland, Keady et al. (1995) revealed that cows fed with fresh Italian ryegrass herbage yielded more milk than cows fed Italian ryegrass silage.

7.4.1.2.2. Yields

The annual yield of Italian ryegrass in Belfast (North Ireland) was about 10 $t_{DM}$/ha when cut, and a little lower when grazed (Camlin and Stewart, 1975). They applied very frequent defoliation: four times annually after spring seeding and eight times during the second year of utilization. Italian ryegrass in their trial was abundantly fertilized with mineral nitrogen. On the Medvednica mountain near Zagreb (Croatia, Leto et al.,2006) Italian ryegrass yielded 7.9 $t_{DM}$/ha in the first year of utilization, and 9.9 $t_{DM}$/ha in the second year. Yields were achieved in three cuts during the vegetation period. There was no yield in the third year, when many other perennial grasses gave reliable and high forage yields at the same location. Westerwolth ryegrass gave yields similar to Italian ryegrass, and surprisingly, lasted for two years. Nitrogen fertilization was 161 kg/ha in the first year and 300 kg/ha of pure nitrogen in the second year. In Canada (Kunelius and Naramsihalu, 1983), both Italian ryegrass and Westerwolth ryegrass acted as spring-seeded annuals, probably because they can't survive the harsh Canadian winter. Both grasses gave three cuts during vegetation. The average annual yield of Italian was 9.8 $t_{DM}$/ha, whilst of Westerwolth was 11.8 $t_{DM}$/ha. Trials were fertilized with only 75 kg/ha of mineral nitrogen. Rainfall during vegetation was from 338 mm to 605 mm, depending on the year. In the field trial of Hickey and Hume (1994) at New Zealand, Italian ryegrass persisted surprisingly long – for three years. It was grown in a mix with white clover. The annual yield of the mix was 12.5 $t_{DM}$/ha, and Italian ryegrass contributed more than 70 %. There was no winter dormancy, it grew even through the winter. In the humid subtropical climate of Louisiana (south of USA)

Westerwolths ryegrass yielded about 10 $t_{DM}$/ha (Redfearn et al., 2005). It was seeded from 20th September till 15th October each year, gave five to seven cuts during vegetation, and ended its vegetation at the end of May or beginning of June.

#### 7.4.1.2.3. Agrotechnical measures

Recommended agrotechnical measures are very similar to the ones for perennial ryegrass. The seeding rate for the establishment of pure stands is 20 to 25 kg/ha (Stjepanović et al, 2008). It is very often seeded with companion legume red clover. When seeding into thinned lucerne crop, the seeding rate is usually 5 to 10 kg/ha. When added into complex long-term mixes, its partial seeding rate is about 10 % from the seeding rate for pure Italian ryegrass stands. The seeding rate for Westerwolth ryegrass is 25 to 35 kg/ha because of larger seeds.
Italian ryegrass removes 270 kg/ha of N with the yield of 10 $t_{DM}$/ha if the CP content is assumed at 17 % in DM. On fertile soils at least 100 kg/ha of N can come from the soil's indigenous nitrogen supply. The rest can be fulfilled either by manuring, mineral fertilization, or from association with legumes (clovers or lucerne). About 30 years ago Italian ryegrass was fertilized with about 250 kg/ha of nitrogen, whilst nowadays the N dosage is restricted to a maximum of 170 kg/ha, according to the Nitrate directive. Some researches have indicated that there is little gain in yield expected above the dosage of 170 kg/ha of N. Greatest part of mineral N should be added to the soil before the onset of spring growth and the rest before the aftermath growths (i.e. after each cutting and herbage removal).
Considering the utilization regime, Stjepanović et al. (2008) recommend mowing the first spring growth at the stage of the end of stem elongation, just before the ear emergence. In such a regime farmers can expect good aftermath growth, excellent forage quality, and high annual yield. In Croatian conditions, Italian ryegrass can give three to four growths without irrigation. With irrigation or with sufficient rainfall during vegetation, it can give up to six growths annually. However, Kunelius and Boswall (2017) recommend cutting the first spring growth at the stage of ear emergence, and always before the bottom leaves start yellowing. The same authors recommend two to four weeks of undisturbed growth before each grazing event, except in summer drought, when farmers should wait for sufficient herbage accumulation.

### 7.4.1.3. Tall fescue

Tall fescue (*Festuca arundinacea* L.) is probably the third grass in popularity in the world, just behind the ryegrasses. It is a tall grass (about 140 cm in height in tasselling). Its flowers develop on the panicle type of inflorescence. It is well suited both for grazing and cutting utilization. It is very resistant to drought, heat, coldness (maintains green color during winter what is important for winter grazing), surplus of water, frequent and deep grazing, and trampling. It tolerates a broad range of soil pH (from acid to alkaline). Its lifespan is about 10 years. The practice of stockpiling the summer and autumn growth for winter grazing is very common in the USA because grazed forage is considered there to be the cheapest forage. In Europe, it is less accepted because of poorer palatability and livestock performance when compared to ryegrasses. Older cultivars had coarse leaves and fungal symbiont that adversely affected livestock performance, whilst the newer cultivars have tenderer leaves and either an absence of the mentioned symbiont or presence of improved symbiont that does not affect the livestock performance. The natural presence of the symbiont enhances the resistance of tall fescue to biotic and abiotic (environmental) stresses.

#### 7.4.1.3.1. Feed value

Content of crude nutrients and energy in tall fescue depends on the developmental stage, as it is in all perennial grasses (Table 22).

Table 22. Forage quality of tall fescue (DLG, 1997.)

| Forage | Stage of development | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Fresh herbage | 1st growth, tasseling | 22 | 15,1 | 25,1 | 5,58 | 63,5 |
| | 1st growth, flowering | 24 | 12,8 | 29,6 | 5,26 | 61,5 |
| | 2nd growth, after 4 weeks | 21 | 20,1 | 20,5 | 7,19 | 78,3 |
| | 2nd growth, after 5 weeks | 24 | 16,4 | 24,1 | 5,55 | 63,0 |
| | 2nd growth, after 8 weeks | 27 | 15,7 | 27,4 | 5,09 | 58,9 |
| | * Calculated according to Maynard (1953) and digestibilities according to DLG (1997.) | | | | | |

Although its analytical parameters (including *in-vitro* digestibility) indicate quality similar to other perennial grasses, livestock performance can be poorer. The reason lies in the presence of natural endophytic fungi that produce ergot-alkaloids that adversely affect livestock, especially during the summer heat. The greatest concentrations of alkaloids are in the bottom parts of the stem and in inflorescences. Avoiding deep grazing (leaving the greater residual herbage after grazing event) and utilization before the emergence of panicle (by cutting or grazing) helps to avoid a greater intake of alkaloids. Seeding newer cultivars free from symbiont or with improved endophyte produces the forage free from alkaloids. Seeding legumes and other grass species into tall fescue pastures dissolve the alkaloids problem.

Mid-lactation Holstein cows fed cut-and-carry fresh herbage of tall fescue infected with natural symbiont milked about 15 kg/cow/day, whilst cows fed endophyte-free tall fescue or lucerne milked about 21 kg/cow/day (Strahan et al., 1987). Cows were supplemented with 4.1 kg/cow/day of concentrate and forages were offered *ad-libidum*. DM intake of infected tall fescue was 7.1 $kg_{DM}$/cow/day, whilst of other forages was about 10 $kg_{DM}$/cow/day. Steers grazed infected tall fescue had an average daily gain (ADG) about 0.5 kg/head/day whilst ones grazed on tall fescue pastures with less than 5 % of infected plants had ADG of about 0.83 kg/head/day (Hoveland et al., 1983; cit Schmidt and Osborn, 1993).

Bouton et al. (2002) have found that lambs have greater ADG when grazed on endophyte-free tall fescue or tall fescue with improved endophyte than lambs grazed on tall fescue infected with a wild strain of endophyte. They have also found that endophyte-free tall fescue can have lesser yield and poorer stand persistence than infected tall fescue.

7.4.1.3.2. Yields

On fertile soils of continental Croatia, tall fescue can give between 7 and 12 t/ha of hay (Stjepanović et al., 2008), depending on rainfall during the vegetation period and on applied agrotechnical measures, mainly N-fertilization. This means that the annual DM yield could be about 10 $t_{DM}$/ha. In the Upper South of the USA tall fescue gives between 3.6 and 8.8 $t_{DM}$/ha, mainly depending on the N-fertilization rate (56 to 224 kg/ha of N; Dobson et al., 1978), and likely due to variations in rainfall and soil fertility. In Georgia (USA), Bouton et al. (2002) achieved between 7.3 and 15.6 $t_{DM}$/ha with N-fertilization of only 123 kg/ha, depending on the location and year of investigation. In Canada, Mason and Lachance (1983) have got about 6.5 $t_{DM}$/ha of tall fescue when fertilized with 150 kg/ha of N. Kallenbach et al. (2003) have stockpiled about 2 $t_{DM}$/ha of tall fescue summer and autumn growth for winter grazing in Missouri (USA).

7.4.1.3.3. Agrotechnical measures

The majority of agrotechnical measures presented for ryegrasses, apply to the tall fescue too. However, for good yields in the first year of utilization, it should be seeded in the late summer term until the end of

August. When seeded later in autumn, first-utilization-year yields are much lower. The seeding rate is from 35 to 40 kg/ha. Nitrogen fertilization recommendations can be similar to the ones for previous grasses. Manuring and associations with legumes can probably be more reasonable than mineral N fertilization. Clovers, besides N-contribution, improve the summer pasture yield and decrease the alkaloid effects on the livestock. Seeding of about 2 kg/ha of white clover seeds or about 5 kg/ha of red clover seeds into tall fescue pasture can bring much of the previously mentioned benefits. Lucerne can also be a good companion to tall fescue, but it has to be seeded in a well-prepared seedbed, together with tall fescue seeds in a pasture seed mix. Considering the defoliation regime, it seems that a regeneration interval of 40 days or longer enables for greater yields than shorter intervals (Brink et al., 2010). However, the authors deem that 30 days of rest period would be quite enough for good yields and quality of tall fescue pasture. The optimum residual height found in New Zealand is about 5 cm, and residual herbage mass about 1.6 $t_{DM}$/ha (Milne et al., 1997). According to Milne et al. (1997), in New Zealand conditions, for the best palatability, the initial herbage mass should be a maximum of 2.8 tDM/ha, rest period during spring 15 days, and during summer 21 days. For hay production, authors recommend mowing the first spring growth of tall fescue at the end of the stem elongation stage, and subsequent growths when there is enough forage accumulated.

#### 7.4.1.4. Cocksfoot (orchardgrass)

Cocksfoot (*Dactylis glomerata* L.) is a long-living tall perennial grass well adapted to temperate zones of the whole world (Samada et al., 2010). Generally, it tolerates drought and heat of mediterranean climates, but doesn't tolerate longer waterlogging. It owes the drought tolerance to deeper rooting when compared to ryegrasses, but not so deep as lucerne. There are available two types of cultivars: continental ones, with relatively good summer growth (although much poorer than lucerne's and red clover's), and mediterranean ones, which are even more drought-tolerant, thanks to their summer dormancy. It is used for the production of mowed forages (hay, haylage, silage) and grazing. It tolerates shadow, so it is often grown in orchards. It is among the highest quality forages while in vegetative stages (before panicle emergence). First spring growth early shows panicle, when stems become hardier and less palatable. Its hay, cut before inflorescence emergence, is much appreciated for calves and horses' diets. For horses, it is more suitable than ryegrasses because it contains less sugars and no entophytic fungi. In milder winters cocksfoot remains green, and therefore suitable for winter grazing (after stockpiling the end-summer and autumnal growth).

7.4.1.4.1. Forage quality

It is suitable for the grazing of all classes of livestock, with exception of the first spring growth upon panicle (tassel) emergence (Hall, 2008). In-detail parameters of forage quality are presented in Table 23.

Table 23. Forage quality of cocksfoot (DLG, 1997.)

| Forage | Developmental stage | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Fresh forage, 1st growth | Panicle emergence | 19 | 19,5 | 21,9 | 6,59 | 73 |
| | Full tasseling | 22 | 17,1 | 25,2 | 6,42 | 72 |
| | Begin of flowering | 26 | 13,5 | 29,9 | 5,91 | 67 |
| | Mid flowering | 30 | 10,9 | 33,7 | 5,52 | 64 |
| | After flowering | 33 | 9,1 | 37,0 | 5,21 | 61 |
| Silage, 1st growth | Panicle emergence | 35 | 20,5 | 23,6 | 6,78 | 75 |
| | Full tasseling | 35 | 17,3 | 25,5 | 5,96 | 67 |
| | Begin of flowering | 35 | 12,4 | 31,6 | 5,71 | 66 |
| | Mid flowering | 35 | 10,6 | 36,3 | 5,13 | 61 |
| Hay, 1st growth | Panicle emergence | 86 | 21,3 | 24,4 | 6,40 | 71 |
| | Full tasseling | 86 | 15,8 | 30,0 | 5,59 | 64 |
| | Begin of flowering | 86 | 11,9 | 34,2 | 4,95 | 58 |
| | Mid flowering | 86 | 10,4 | 37,3 | 4,70 | 57 |
| | * Calculated according to Maynard (1953) and digestibilities according to DLG (1997.) | | | | | |

In some comparative trials with tall fescue, livestock performance was better when fed cocksfoot than when fed tall fescue. Steers grazed cocksfoot in Tennessee (the USA, McLaren et al., 1983) had ADG of 0.825 kg/head/day whilst ones grazed tall fescue had ADG of 0.500 kg/head/day. Suckling calves on cocksfoot pasture with their mothers in South Indiana (USA) had ADG of 0.80 kg/head/day, whilst the ones on tall fescue pasture with their mothers had ADG of 0.54 kg/head/day (Peritz et al., 1979).

7.4.1.4.2. Yield

On Medvednica mountain near Zagreb (Leto et al., 2006), upon the late-summer seeding time in the previous year, cocksfoot gave relatively low yield in the first year of utilization, only 7.3 $t_{DM}$/ha. Yields were much better in the second and third years, 13.7 and 10.3 $t_{DM}$/ha, respectively, what was similar to many other perennial forages. These results indicate that cocksfoot needs about one year to reach its full productivity, even when seeded in the late-summer seeding term. Cocksfoot was utilized by mowing, in three cuts during the vegetation season. Research by Andreata-Koren et al. (2009) on the same location has shown that cocksfoot productivity is greater when grazed by cattle than by sheep. The reason lies in the fact that cocksfoot has somewhat raised bunch which becomes injured upon deep grazing of sheep. In Wisconsin (the USA, Brink et al., 2010), cocksfoot yielded between 5.5 and 8.5 $t_{DM}$/ha despite the abundant mineral N fertilization (201.6 kg/ha of pure N). In Canada (Papadopoulos et al., 2001) cocksfoot yielded between 7.1 and 12.3 $t_{DM}$/ha, depending on the year of research. In the mediterranean climate of Isparta (west of Turkey; Albayrak and Türk, 2013), cocksfoot yielded only about 4.7 $t_{DM}$/ha while lucerne yielded about 15.5 $t_{DM}$/ha. These results indicate that lucerne had much better drought resistance than cocksfoot.

7.4.1.4.3. Agrotechnical measures

Generally, recommended measures are similar to those for previously presented perennial grasses. Stjepanović et el. (2008) recommended a seeding rate of 25 to 30 kg/ha. In spring, it should be grazed frequently to prevent inflorescence emergence. For a quick regrowth, optimal residual height after defoliation is somewhat greater than for other perennial forages, about 7 to 10 cm above the soil surface, because of its raised bunch. A two-year trial in Pennsylvania (USA; Mislevy et al., 1997) achieved the highest forage yields when cocksfoot was mowed in flowering, but the achieved forage quality and aftermath yield were poor. They achieved optimal quality and annual yield when the first growth was cut in the stage of stem elongation. Thus, the subsequent regrowths were quick and high-yielding. Based on their results they recommended defoliation of the aftermaths at the plant height between 20 and 30 cm. They also revealed that frequent defoliation (when plants are 10 to 15 cm tall) significantly diminishes aftermath yields and cumulative annual yield. Considering the N-fertilization, Hall (2008) recommends about 150 kg/ha split into three applications: first before the spring growth, and the rest after the first and second cut are taken. Papadopoulos et al. (2001) in Canada achieved high cocksfoot yields with 160 kg/ha of nitrogen (7.7 to 12.3 $t_{DM}$/ha, depending on the year of research). Insignificantly lower yields they achieved without N-fertilization, but with accompanying cocksfoot with white clover (7.1 to 9.0 $t_{DM}$/ha). The seeding rate of white clover was 5 kg/ha, and cocksfoot 5 kg/ha too. P and K fertilization was adjusted to their availability in soil. In Connecticut (USA; Kanneganti and Klausner, 1994), cocksfoot yielded 3.8 and 5.3 $t_{DM}$/ha after spreading the farmyard manure in the 150 kgN/ha equivalent, before spring growths. With the addition of 75 kg/ha of mineral N, annual yields raised to 6.2 and 9.2 $t_{DM}$/ha, depending on the year of research. The addition of 150 kgN/ha raised yields to 7.9 and 11.1 $t_{DM}$/ha.

#### 7.4.1.5. Meadow fescue

According to Stjepanović et al. (2008), meadow fescue (*Festuca pratensis* Huds.) is tall (in tasselling about 120 cm in height or higher), long-living perennial grass, with a lifespan of 8 to 10 years. It is popular both for mowing and for grazing and is considered to be among the highest-quality grasses. In its first year, it has a slower development rate than ryegrasses, but faster than tall fescue. It forms tassel only in the first spring growth. It starts the growth very early in spring, and tassels relatively late (in Croatian conditions in June, after all other perennial grasses, except cat’s tail), thus maintaining the vegetative stage for a long period. Its drought tolerance is somewhat lesser than that of tall fescue and cocksfoot. For high yields, it needs more moist conditions, a more humid cooler climate and higher elevation. However, it can be found in spontaneous plant communities even in the Mediteranean grasslands of Croatia, but only on locations where the soil is moister (around depressions of terrain and water flows, author’s observation). It tolerates waterlogging for up to four weeks during vegetation (Stjepanović et al., 2008). It tolerates both heavy and light soils, but only if there is enough water. However, its drought tolerance is better than that of ryegrasses.

7.4.1.5.1. Feed value

The chemical parameters of meadow fescue's quality are very similar to other perennial grasses (Table 24).

Table 24. Feed value of meadow fescue (DLG, 1997.)

| Forage | Developmental stage | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Fresh herbage, 1st spring growth | Fool tasselling | 22 | 18,9 | 23,7 | 6,37 | 71,1 |
| | Tassel emergence | 24 | 13,6 | 28,6 | 5,88 | 67,3 |
| | Full tasselling | 26 | 12,3 | 31,5 | 5,62 | 64,6 |
| | After flowering | 29 | 9,9 | 35,7 | 4,83 | 57,4 |
| Silage, 1st spring growth | Tassel emergence | 35 | 17,4 | 22,5 | 6,71 | 74,4 |
| | Full tasselling | 35 | 16,1 | 26,2 | 6,23 | 66,9 |
| | Flowering | 35 | 11,1 | 35,2 | 5,57 | 65,3 |
| Hay, 1st spring growth | Tassel emergence | 86 | 21,5 | 22,5 | 6,77 | 75,4 |
| | Full tasselling | 86 | 12,0 | 28,2 | 5,92 | 75,5 |
| | Begin of flowering | 86 | 8,0 | 33,1 | 5,91 | 68,0 |
| | Mid flowering | 86 | 10,6 | 35,0 | 5,62 | 65,3 |
| | * Calculated according to Maynard (1953) and digestibilities according to DLG (1997.) | | | | | |

In a three-year research of Schaeffer et al. (2014) in Wisconsin (USA), steers grazed meadow fescue had greater ADG than steers grazed tall fescue (0.8 to 1.15 kg/head/day vs. 0.7 to 0.95 kg/head/day, depending on the year of research and association with white clover of pure grass pasture). Initial body weight was about 260 kg/head.

7.4.1.5.2. Forage yields

In the field research of Leto et al. (2006) on Medvednica mountain, meadow fescue yielded 9.1 $t_{DM}$/ha in the first year (more than cocksfoot), 14.9 $t_{DM}$/ha in the second year and 7.74 $t_{DM}$/ha in the third year (the year with less rainfall). The grass was utilized in a three-cut regime. In Finland (Niemeläinen et al., 2008) meadow fescue yielded 8.5 $t_{DM}$/ha in the first year, 8 $t_{DM}$/ha in the second year and 7.6 $t_{DM}$/ha in the third year. Its yields in the second and third year were lower than of tall fescue. Both grasses overwintered very well the Finnish harsh winters. In the humid climate of Wisconsin (the USA, Casler et al., 2008), meadow fescue yielded 4.6 to 6.7 $t_{DM}$/ha (depending on the cutting height and variety) in a six-cut regime, and 5.8 to 8.9 $t_{DM}$/ha in a three-cut regime. In the Mediterranean climate of Isparta (west of Turkey, Albayrak and Türk, 2013), meadow fescue yielded about three to four times less than lucerne.

7.4.1.5.3. Agrotechnical measures

Stjepanović et al. (2008) recommend seeding in the late-summer seeding term, preferably in the second half of August in continental Croatian conditions. Recommended seeding rate is 30 to 40 kg/ha. It should be fertilized with up to 200 kg/ha of pure nitrogen. Authors assume that just like all other perennial grasses, meadow fescue would yield quite well if grown in association with sufficient share of legumes, and/or fertilized with farmyard manure. Considering the cutting regime, Stjepanović et al. (2008) recommend cutting the first spring growth at the end of stem elongation stage, and aftermaths after six weeks of undisturbed growth. Authors deem that a rest period of 30 days could be very appropriate, like it is for the majority of perennial grasses.

7.4.1.6. Cat's tail (Timothy grass)

According to Lacefield et al. (2000), a cat's tail is grass adapted to cooler and humid climates. It has a shallow root system. More than 70 % of the annual yield it creates in the first spring growth. It is mainly cultivated for hay production, which is highly appreciated in stalled horses' nutrition. Its hay is less prone to mold than legume hay, it has no surplus of protein neither sugars (what is important to avoid laminitis). It is highly recommended to horses prone to colic. Horses usually chew cat's tail hay longer than hay of other grasses what resembles natural activity during grazing, thus improving the psychical health of stalled horses. According to Stjepanović et al. (2008), it is among the latest grasses considering the onset of tasselling (it occurs in June in Croatian conditions). It is very cold resistant. Its lifespan is about five years, but in hills and mountains it can last much longer, about 10 years. It does not tolerate dry, acidic, and poor fertility soils. Deep grazing of sheep suppresses the cat's tail and shortens its lifespan to two or three years.

7.4.1.6.1. Feed value

Its feed value strongly depends on the developmental stage, just like in other grasses (Table 25).

Table 25. Feed value of cat's tail (DLG, 1997.)

| Forage | Developmental stage | ST (%) | SB (% u ST-u) | SV (% u ST-u) | NEL ($MJ/kg_{ST}$) | TDN* (% u ST-u) |
|---|---|---|---|---|---|---|
| Fresh herbage, 1st spring growth | Početak metličanja | 22 | 17,1 | 21,1 | 7,11 | 78,0 |
| | Puno metličanje | 24 | 13,8 | 26,4 | 6,13 | 69,1 |
| | Početak cvatnje | 27 | 11,9 | 30,8 | 5,90 | 67,9 |
| | Sredina cvatnje | 29 | 10,3 | 34,1 | 5,76 | 67,0 |
| | Nakon cvatnje | 33 | 9,1 | 38,1 | 5,56 | 65,4 |
| Silage, 1st spring gowth | Početak metličanja | 35 | 17,4 | 22,5 | 6,74 | 75,4 |
| | Puno metličanje | 35 | 15,5 | 28,5 | 6,28 | 71,1 |
| | Početak cvatnje | 35 | 12,6 | 32,5 | 5,73 | 66,0 |
| | Sredina cvatnje | 35 | 11,1 | 36,5 | 5,80 | 67,8 |
| Hay, 1st spring growth | Početak metličanja | 86 | 13,9 | 27,9 | 6,17 | 69,7 |
| | Puno metličanje | 86 | 12,1 | 30,1 | 5,93 | 68,3 |
| | Početak cvatnje | 86 | 10,2 | 33,3 | 5,31 | 62,2 |
| | Sredina cvatnje | 86 | 9,7 | 37,4 | 5,17 | 61,5 |

* Izračun prema Maynardu (1953.) i probavljivosti prema DLG-u (1997.)

Research conducted by Villeneuve et al. (2013) in Canada, has shown that pasture, silage, or hay of cat's tail, used as a basic part of the ratio (about 13.9 $kg_{DM}$/head/day), with moderate addition of concentrate (7.2 kg/head/day, with a share in the daily DMI of about 1/3) allow high milk yield of Holstein cows during the last third of lactation (about 25 kg/cow/day). Cows pastured on cat's tail were most productive, somewhat lesser ones fed silage, and least productive were those fed hay. Year-old steers grazed cat's tail Canada had ADG 1.13 kg/head/day (Rode and Pringle, 1986), without any concentrate supplementation (except mineral salt). DMI in their research was about 3 % of BW. Heifers fed cat's tail hay in Canada, without supplementation, had an ADG of 0.78 kg/head/day (Martineau et al., 1994).

7.4.1.6.2. Forage yields

In the three-year research of Leto et al. (2008) on Medvednica Mountain, the cat's tail yielded about 10 $t_{DM}$/ha. In Canada, it yielded between 8 and 10 $t_{DM}$/ha (Malhi et al., 2004). When planning the potential forage yield of a cat's tail, one should consider its sensitivity to drought.

#### 7.4.1.6.3. Agrotechnical measures

Considering the seeding term, all mentioned for previous grasses is applicable for a cat's tail too. The seeding rate according to Lacefield et al. (2000) is about 5 kg/ha, whilst according to Stjepanović et al. (2008) is about 10 kg/ha. The nitrogen rate should be similar to previous grasses, i.e. about 170 kg/ha annually. For high forage yields of cat's tail without mineral nitrogen addition there would be required minimal share of legumes in the mixed stand, at least 25 %, but for maximum yields, there would be required up to 40 % of legumes (Lacefield et al., 2000).

#### 7.4.1.8. Other cool-season perennial grasses

At the seed market, there could be found reed canary grass (*Phalaris arundinacea* L.), smooth brome (*Bromus inermis* Leyss), Kentucky bluegrass (*Poa pratensis* L.), red fescue (*Festuca rubra* L.) and sheep fescue (*Festuca ovina* L.). Reed canarygrass is a tall grass popular in the USA and Australia due to its drought tolerance and flooding tolerance. In some parts of the world it is considered invasive species, and there is required to prevent its seed set by timely defoliation. Smooth brome is a tall grass too, that gives high quality forage. It is tolerant to drought and temperature extremes. It has lost popularity because it has poor regrowth after the spring growth maximum. Kentucky bluegrass is a short, sod-forming grass (it spreads by stolones and forms interconnected sod). Its forage is of high-quality, and it has quick regrowth after defoliation if there is enough available water. It tolerates low and frequent grazing. Its yield potential is lower than that of tall grasses, but its drought resistance is better than that of ryegrasses. For good yields, it requires good soil quality. Due to expensive seed, it is usually seeded as a minor component of complex grass-clover mixes for grazing. Red fescue is a very resistant short grass for pastures. Its forage quality is somewhat poorer than that of Kentucky bluegrass. Due to its drought resistance, it is popular in the Croatian Adriatic region. Sheep fescue is usually found in mountainous grasslands due to its tolerance to shallow and low fertility soils. It has low yield potential but can be satisfactory as a component of mountain pastures. Besides the aforementioned grass species, there can be found interspecies hybrids between ryegrasses (*Lolium* species) and fescues (*Festuca* species). Their crosses are marketed as *Festulolium* hybrids that combine the high quality of ryegrasses and resistances of fescues.

### 7.4.2. Warm-season perennial grasses

Among perennial grasses, the warm-season ones are recognized for their better growth during the summer heat. Their maximum growth occurs at beginning of summer, when cool-season grasses approach their summer minimum of growth (summer slump). During the mid-summer, they still grow, except in the case of pronounced drought, which can limit their growth too. They employ a $C_4$ type of photosynthesis that is more effective at higher environmental temperatures. Most important species are bermudagrass (*Cynodon dactylon* L.), johnsongrass (*Sorghum halepense* L.), switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardi* Vit.) and indiangrass (*Sorgastrum nutans* L.).

#### 7.4.2.1. Bermudagrass

According to Guerrer et al. (1984) and Scarabrough et al. (2006), bermudagrass is the main warm-season perennial forage grass in the south of the USA, and it is used both for grazing and haying. It gave satisfactory pasture in Texas (USA; Guerrero et al., 1984), and enabled ADGs of grazed fattening cattle between 0.30 and 0.94 kg/head/day, depending on the variable digestibility of bermudagrass and variable herbage allowance to the grazed cattle. Young vegetative bermudagrass and high pasture allowance (7 % of BW) were associated with high ADGs, while the low ADGs were achieved at old bermudagrass and low herbage allowances (3 % of BW).

Annual yields of about 10 $t_{DM}$/ha were achieved in Texas (Holt and Conrad, 1986) in frequent defoliation regime (every 14 days). Somewhat higher yields were achieved at defoliation every 28 days (about 12.8 $t_{DM}$/ha), higher at defoliation every 42 days (15.5 $t_{DM}$/ha) and the highest at defoliation every 56 days (16.6 $t_{DM}$/ha). The highest forage digestibility was at the shortest (14-days) rest period (about 64 %), and the least at long rest periods (about 55 %).
Bermudagrass can be established by seeding from March till May in the south of the USA, with a seeding rate of about 6 kg/ha of live shelled seeds (Lemus, 2018).

#### 7.4.2.2. Johnsongrass

Fattening cattle grazed on johnsongrass in Alabama (USA; Rankins and Bransby, 1995) gained between 0.41 and 0.55 kg/head/day. Herbage had between 17.4 and 15.0 % CP and *in-vitro* digestibility between 62.7 and 58.8 %. The annual forage yield of johnsongrass can be over 10 $t_{DM}$/ha, or over 2 $t_{DM}$/ha, depending on the stocking rate and intensity of defoliation. High and continuous stocking rates suppress the johnsongrass's regrowth and decrease cumulative annual forage yield. In the trial of Rankins and Bransby (1995), johnsongrass was established by a seeding rate of 28 kg/ha, and was either manured or fertilized with mineral N, two times during vegetation with 67 kg/ha of pure N.

#### 7.4.2.3. Indian grass, switchgrass and big bluestem

Fattening cattle grazed switchgrass in Nebraska (the USA, hot summers and cold winters) gained about 0.45 kg/head/day when grazed in tasselling, and 0.77 or 0.98 kg/head/day when grazed vegetative switchgrass (Anderson et al., 1988). Calves gained 0.97 kg/head/day when suckled cows grazed on big bluestem in Nebraska too (Blasi et al., 1991), without any concentrate supplementation. The applied stocking rate was about 2 AU/ha. In a single-cut harvest regime, these grasses can be quite productive, between 10 and 20 $t_{DM}$/ha, whilst in a frequent defoliation regime (e.g. every 30 days), their yield can be very low, only about 5 $t_{DM}$/ha for switchgrass, or even lesser for others. These grasses develop very slowly, so it is reasonable to grow silage maize as a companion crop in the seeding year. The seeding rate for switchgrass is about 9 kg/ha, and for indiangrass and big bluestem about 4 kg/ha (Barnhart, 1994), i.e. with 40 to 50 live seeds per $m^2$.

## 7.5. Grass-legume mixes

All aforementioned perennial grasses and legumes can be grown either in monoculture or in mutual mixes. According to Hall and Vough (2007), agrotechnical measures for monocultures are simpler because all plants in a crop simultaneously come to the optimal developmental stage for utilization, while it happens rarely in grass-clover mixes. Chemical weed control is feasible in monocultures, while in grass-clover mixes almost impossible. In grass-legume mixes grasses can outcompete legumes, what decreases the protein content, summer growth, and drought tolerance. However, the production of grass-clover mixes can offer many advantages over monocrops (Hall and Vough, 2007):

1. legumes bind atmospheric nitrogen into plant-available compounds, thus decreasing the need for mineral nitrogen fertilization;
2. grass-legume mixes usually have greater protein concentration and digestibility than pure grass crops;
3. legumes grow better than cool-season grasses during summer, thus providing extended grazing during summer;
4. grass-legume mixes are less prone to weed colonization than mono-crops;
5. grass-legume mixes provide for lesser soil erosion;

6. grass-legume mixes dry faster during hay curing;
7. grass-legume mixes are more adaptable to varying soil conditions;
8. grass-legume mixes have a lower bloat risk than monocrop legumes;
9. legumes contain more Ca and Mg than grasses thus preventing the grass tetany;
10. grasses decrease the lodging of legumes.

Grass-legume mixtures offer better-balanced forage than pure stand legumes or grasses. Namely, grasses are usually richer in energy and digestible fiber, whilst legumes are richer in protein. Grasses are much appreciated by farmers that are pasturing their livestock. Namely, grasses are evolutionary the most natural feed for large herbivores since the grasses comprise the largest share of biomass on permanent grasslands, where the large herbivores evoluted. In grazing mixes, besides grass and legumes there can be included some herbs, like grazing chicory (*Cichorium intybus* L.), narrow-leaf plantain (*Plantago lanceolata* L.), and common yarrow (*Achillea millefolium* L.) which provide for better internal parasite control, bloat reduction, more Ca and Mg, and more reliable summer herbage growth.

For establishing grass-legume mixes, choice of grass and legume species should be in accordance with soil, climate, and way of utilization, since all the aforementioned grass and legume species have some particularities considering their requirements for environmental conditions, suitability for grazing and/or cutting, lifespan and effects to livestock performance. The respective share of each species should also be targeted according to the specific aims. For example, a sufficient share of legumes will provide for good yields without N-fertilization, better performance of livestock and better summer growth than will pure grasses. Also, a sufficient share of grasses will speed-up drying for hay production, lower the risk from frothy bloat and provide more energy than legumes. Some producers favor complex grass-clover mixes with many species include. The advantage of complex mixes is that various species have various adaptability to varying soil conditions at seeded plot, and complex mixes provide for greater variety in the offered allowance to the livestock. The advantage of simple mixes is their simplicity – you do not have to collect many sorts of seeds and mix them, and they are usually assembled from the most productive species only, with the cheapest seed.

Farmers should bear in mind that the share of seeded species will be prone to changes during the utilization period of the established grass-clover mix due to competition among seeded species and various adaptability to soil and climate conditions.

Calculation of partial seeding rates for each component can be done by using the equation below:

$$SRp\ [kg/ha] = SR\ [kg/ha] \times TS\ [\%]/100$$

Where the SRp is the partial seeding rate of each grass-clover mix component, SR is the seeding rate of each component for the pure stand crops, and TS is the targeted share of each component.

## 8. PERMANENT GRASSLANDS

Grasslands, according to UNESCO's definition, are presented with the land area covered with herbaceous plants with less than 10 % of trees and shrubs (Reheul et al., 2010). According to the compilation of Reheul et al. (2010), grasslands occupy 52.5 million km$^2$ on Earth or 40.5 % of the land (Greenland and Antarctica excluded). According to Hejcman et al. (2013), permanent grasslands can be natural (or primary) and semi-natural (or secondary). Natural grasslands occupy zones where forests could not spread naturally, due to adverse climatic conditions (drought, hot or cold) or due to high elevations. Maintenance in the state of grassland is helped there by wild herbivores (bisons, antelopes, cattle, etc.). Therefore, they are also called climatogenic grasslands. Semi-natural or secondary grasslands are anthropogenic, and they appeared after clearing the forests by lodging or fire. There is necessary human activity in order to prevent their natural

succession to the forest (either cutting or grazing livestock). Perennial grasslands of Western and Central Europe are mainly anthropogenic (Bredenkamp et al., 2002), whilst in Eastern Europe, natural grasslands (stepes) occupy a considerable share (Hejcman et al., 2013). Semi-natural grasslands of central Europe have annual productivity between 1 and 10 $t_{DM}$/ha (Hejcman et al., 2013).
Croatia is a country with a considerable share of permanent grasslands in agricultural land. According to Šoštarić-Pisačić and Kovačević (1968), Croatia had 1.6 million hectares of permanent grasslands what was 48 % of total agricultural land (3.4 million ha). Of the total permanent grasslands area, meadows were 0.4 million ha and pastures near 1.2 million ha (DZS, 2003). Less than half of this area is utilized nowadays, only about 0.6 million ha (DZS, 2015).
Grasslands have remained only on less valuable land in Croatia, i.e. on soils that are problematic for cultivation (clayey soils, stony soils, gravels, shallow soils, very acidic soils, saline soils, poorly drained soils), on problematic terrains (hilly landscape, steep inclinations, high elevations), on areas with adverse water regime (temporal flooding, high level of subsoil water, wet soils) and in too humid areas. Permanent grasslands of the USA's rangeland have remained on poor fertility and shallow soils, very often suffering from drought. Forage production of permanent grasslands is much lower than that of arable forage crops, but their value is very appreciated because of their extensive area, low level of required inputs, simple agronomy, suitability for cheap utilization by grazing livestock, and many environmental services that they provide. Permanent grasslands host much greater biodiversity than arable crops (plants, insects, birds, mammals), protect against soil erosion, mainly do not require pesticides, consume considerably fewer fossil fuels than arable crops, and sequester atmospheric carbon, whilst arables release carbon upon their hummus mineralization. In addition, permanent grasslands are far more attractive than arable land to modern urban people.
Permanent grasslands in Croatia can be classified into five classes:

1. plane and valley grasslands that yield about 3 to 5 t/ha of hay equivalents, and with fertilization they could probably yield up to 10 t/ha (Todorić and Gračan, 1987);
2. hilly grasslands that yield about 3 to 4 t/ha of hay equivalents, with potential improvement by fertilization (Todorić and Gračan, 1987). They take place on shallower soils and very often on inclinated terrains;
3. mountainous grasslands that yield about 0.3 to 1.4 t/ha of hay equivalents (Todorić and Gračan, 1987). They take place on shallow or very shallow soils, mainly inclined, very often with visible stones and rocks. They occur in the mountainous type of climate (cooler and with plenty of precipitation). Soil erosion by water and wind is pronounced;
4. karst grasslands that yield about 0.5 t/ha of hay equivalents (very free estimation of authors), when browse from shrubs and bushes are included, but the annual yield can be much lesser than the estimated average. They occur usually on very shallow soil with many visible stones and rocks. Their unique characteristic is that they comprise many aromatic and medicinal plants that beneficially affect the health of pastured animals. In Croatia, they are spread mainly in the Adriatic region with a Mediterranean type of climate (hot and dry summers, and mild and rainy winters). Here is also pronounced soil erosion;
5. marsh grasslands, that are periodically flooded. They are productive, but the forage is of poor quality.

The authors were not capable to estimate the respective land area of each of the aforementioned grassland classes in Croatia.
Besides **permanent** grasslands, there can be established **perennial** grasslands on arable land, and they are usually called leys. Temporal conversion of arable land (for 2 to 5 years) into perennial pasture can provide many ecosystem services and restore degraded soil fertility. Conversion of arable soil into short-term perennial grassland (for 2 to 5 years) was traditional means for reparation of soil fertility and control of perennial arable weeds in Western Europe (Nevens and Rehaul, 2003). Ajayi and Horn (2016) have confirmed in a field trial in Germany that conversion of degraded arable soil into perennial grassland repairs the soil's structure and forms a system of stabile pores. Such a conversion has also improved the mechanical

and hydraulic properties of soil (volume of pores, capacity for water and hydraulic conductivity). Short-term conversion of arable soil into a three-year grazing lay has favorably affected the subsequent maize crop yield and N-nutrition (Nevens and Reheul, 2001a). Namely, after plowing the short-term grazing lay, they achieved a silage maize yield of 20 $t_{DM}$/ha without N-fertilization, which was similar to the maize yield grown in monoculture and fertilized with 180 kg/ha of nitrogen.

8.1. Feed value of herbage from permanent grasslands

The feed value of herbage from permanent grasslands mainly depends on the botanical composition of the present herbage and the developmental stage of present plants. Permanent grasslands are usually rich in plant species, which can be classified into several agronomically important classes in Croatia (Šoštarić-Pisačić and Kovačević, 1968):

1. high-quality grasses (*Arrhenatherum elatius*, *Dactylis* sp., *Lolium* sp., *Poa* sp., some *Festuca* sp., some *Bromus* sp., and others);
2. legumes (perennials: *Medicago* sp., *Trifolium* sp., *Corniculatus* sp., and others, and annuals: *Vicia* sp., *Lathyrus* sp., *Coronilla* sp., and others);
3. poor grasses (some *Festuca* sp. and others) and grass-like marsh plants (*Cyperaceae* and *Juncaceae*);
4. forbs or herbs (*Achillea* sp.., *Plantago* sp., *Taraxacum officinale*, *Daucus carota*, *Cichorium intybus*, *Rumex* sp. and others);
5. mosses and lichenes.

The presence of the aforementioned forbs is much appreciated in permanent grasslands because they contain more Ca and Mg than grasses, they grow better than grasses during summer, they are more drought resistant and they contain aromatic and bitter compounds that act beneficially to animal health. They are well known for their anti-parasitic properties, very often seen in grazed horses for example (cleaning the intestinal parasites - helminths).
Besides the aforementioned five classes, Todorić and Gračan (1986) have presented **weeds on grasslands** that comprise poisonous, noxious, harmful and spiky plant species:

1. poisonous and excessively bitter plant species (*Aristolochia clematitis*, *Cicuta virosa*, *Conium maculatum*, *Colchicium autumnale*, *Equisetum* sp., *Anemone* sp., *Caltha palustris*, *Cardamine* sp., *Galega officinalis*);
2. harmful plant species (*Allium* sp., *Sinapis* sp., *Thlaspi arvensis*, that cause the milk odor like of garlic; *Melampyrum*, *Myosotis*, *Gallium*, *Euphorbia* sp. that give bluish milk color; *Rumex* and *Cirsium* that cause the quick milk coagulation; *Lepidium*, *Galeopsis*, *Camelina* that give unpleasant smell to the meat);
3. spiky and hairy plant species that livestock avoids eating (*Cirsium* sp., *Ononis spinosa*, *Symphytium officinale*);
4. hard-stemmed plant species (*Juncaceae* sp, *Carex* sp.).

The botanical or floristic composition of permanent grasslands depends on their position, origin, climate and intensity of utilization. Intensively utilized grassland (frequently mowed, grazed and fertilized) comprise considerably less count of plant species than extensively utilized grasslands (rarely mowed or grazed; Šoštarić-Pisačić and Kovačević, 1968).

The feed value of forage from permanent grasslands can be very high if utilized in vegetative stages, but it usually decreases with the senescence of present plants (Table 26). Silage (Table 27) and hay (Table 28) from permanent grasslands are of lower quality due to losses that occur during the ensiling and haying. Frequently utilized grasslands usually produce herbage of higher quality than rarely utilized ones, at least considering crude protein content, digestibility and energy value.

Table 26. Average feed value of herbage from permanent grasslands in Germany (DLG, 1997). The botanical composition includes cool-season grasses, legumes and herbs.

| Type of grassland | The developmental stage of prevailing grasses | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Prevail short grasses, annually 4 and more deherbations | Stem elongation | 16 | 23,5 | 17,2 | 7,38 | 79,1 |
| | Earing/Tasselling | 18 | 20,7 | 23,1 | 6,58 | 72,5 |
| | Begin of flowering | 22 | 18,7 | 26,1 | 6,30 | 70,6 |
| | Aftermath, after 5 weeks | 18 | 21,3 | 22,9 | 6,09 | 67,4 |
| Prevail tall grasses, annually 2 to 3 deherbations | Begin of earing/tasselling | 17 | 18,0 | 19,5 | 6,90 | 75,5 |
| | Full earing/tasselling | 18 | 15,2 | 24,7 | 6,27 | 70,4 |
| | Begin of flowering | 21 | 13,0 | 28,8 | 5,88 | 67,2 |
| | Mid to end of flowering | 23 | 10,8 | 32,3 | 5,50 | 64,2 |
| | Aftermath, after 5 weeks | 20 | 16,6 | 24,7 | 5,95 | 66,8 |
| | * Calculated according to Maynard (1953) and digestibilities according to DLG (1997) | | | | | |

Table 27. Average feed value of silage from permanent grasslands in Germany (DLG, 1997.)

| Type of grassland | The developmental stage of prevailing grasses | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Prevail short grasses, annually 4 and more deherbations | Stem elongation | 35 | 23,5 | 17,2 | 7,38 | 79,1 |
| | Earing/Tasselling | 35 | 20,7 | 23,1 | 6,58 | 72,5 |
| | Begin of flowering | 35 | 18,7 | 26,1 | 6,30 | 70,6 |
| | Aftermath, after 5 weeks | 35 | 21,3 | 22,9 | 6,09 | 67,4 |
| Prevail tall grasses, annually 2 to 3 deherbations | Begin of earing/tasselling | 35 | 16,5 | 22,1 | 6,69 | 73,9 |
| | Full earing/tasselling | 35 | 14,8 | 26,4 | 5,89 | 67,0 |
| | Begin of flowering | 35 | 13,0 | 29,9 | 5,76 | 66,3 |
| | Mid to end of flowering | 35 | 11,0 | 33,4 | 5,38 | 62,8 |
| | Aftermath, after 5 weeks | 35 | 15,7 | 26,0 | 5,68 | 64,7 |
| | * Calculated according to Maynard (1953) and digestibility according to DLG (1997) | | | | | |

Table 28. Average feed value of hay from permanent grasslands in Germany (DLG, 1997.)

| Type of grassland | The developmental stage of prevailing grasses | DM (%) | CP (% in DM) | CF (% in DM) | NEL ($MJ/kg_{DM}$) | TDN* (% in DM) |
|---|---|---|---|---|---|---|
| Prevail short grasses, annually 4 and more deherbations | Full earing/tasselling | 86 | 12,6 | 27,5 | 6,05 | 68,5 |
| | Begin of flowering | 86 | 11,1 | 30,3 | 5,73 | 65,9 |
| | Mid to end of flowering | 86 | 10,0 | 33,3 | 5,07 | 59,6 |
| | Aftermath, after 5 weeks | 86 | 14,2 | 27,3 | 5,52 | 64,3 |
| Prevail tall grasses, annually 2 to 3 deherbations | Full earing/tasselling | 86 | 10,6 | 29,4 | 5,32 | 61,8 |
| | Begin of flowering | 86 | 9,4 | 32,4 | 4,93 | 58,3 |
| | Mid to end of flowering | 86 | 9,1 | 35,6 | 4,55 | 54,5 |
| | Aftermath, after 5 weeks | 86 | 13,3 | 28,4 | 5,28 | 60,7 |
| | * Calculated according to Maynard (1953) and digestibility according to DLG (1997) | | | | | |

Better quality of frequently utilized grasslands comes out of a greater share of short grasses and leaves, and consequently, a lesser share of stems in the grassland's yield. High quality of aftermath (regrowth after the 1st growth is taken) is also the consequence of a great share of leaves and a low share of stalks.

Steers fed meadow hay without concentrates supplementation in Nebraska (USA; Worrell et al., 1986) gained 0.81 kg/head/day when fed hay from the first spring cut (cut at the end of June, grasses were mainly at the end of the vegetative stage and beginning of the generative stage), 0.50 kg/head/day when fed hay cut at the beginning of August, and 0.41 kg/head/day when fed hay cut at the end of September. DMI was also highest for the hay from the first spring growth (2.41 % of BW), medium for mid-summer hay (2.24 % of BW) and the lowest for autumn hay (2.16 % of BW). Fattening cattle grazed on high-yielding permanent grasslands of Western Europe (Great Britain, Germany and France) enables the ADGs between 0.58 and 0.98 kg/head/day without concentrate supplementation (Isselstein et al., 2007). Such gains were achieved on grasslands that received about 500 mm of rainfall from April to October, the initial herbage mass was between 1.9 and 4.3 $t_{DM}$/ha, and the stocking rate was between 1.0 and 2.4 LU/ha. Lower livestock gain is expected on low yielding grasslands, due to smaller bites and longer time spent in a search for feed.

## 8.2. Basics of grassland plants biology that affect the maintenance of grasslands

Knowing the basics of the biology of grassland plants is necessary for understanding the principles of grazing management. Plants use energy from sunlight to produce sugars from the $CO_2$ caught from the atmosphere, with the consequential release of $O_2$ in the surrounding atmosphere, in the process well known as photosynthesis. All building elements (amynoacids, proteins, cellulose, etc.) and biologically active compounds (vitamins, hormones, enzymes, etc.) plants synthesize by themselves, whilst they uptake minerals from the soil. The primary role of leaves is to do photosynthesis thus supplying the plant with energy. Roots and bottom parts of plants play important role in storing the energy reserves for the first growth after winter or summer dormancy and for the aftermath (regrowth after defoliation). Plants need the required rest period between defoliations, to replenish the energy reserves from photosynthetically active leaves for their vigorous regrowth. Periodical defoliation stimulates the tillering of grasses, keeps grasses and legumes in vegetative or early generative stages (favorable for utilization) and suppresses the weeds. Therefore, for maintenance of permanent or perennial grasslands (or grass-clover mixes) in a favorable condition (vigorous, high-yielding, high-quality, weed-free, with dense sward, with no bare ground areas) it is crucial to conduct the optimal defoliation regime. For most perennial forages (grasses and legume), the optimal rest period between defoliations is about 30 days. However, in the case of summer or winter dormancy, the rest period has to be extended.

Temperate grasslands usually have their maximum growth during spring, minimum from mid- to end-summer, and slight autumnal growth before winter dormancy (Figure 9).

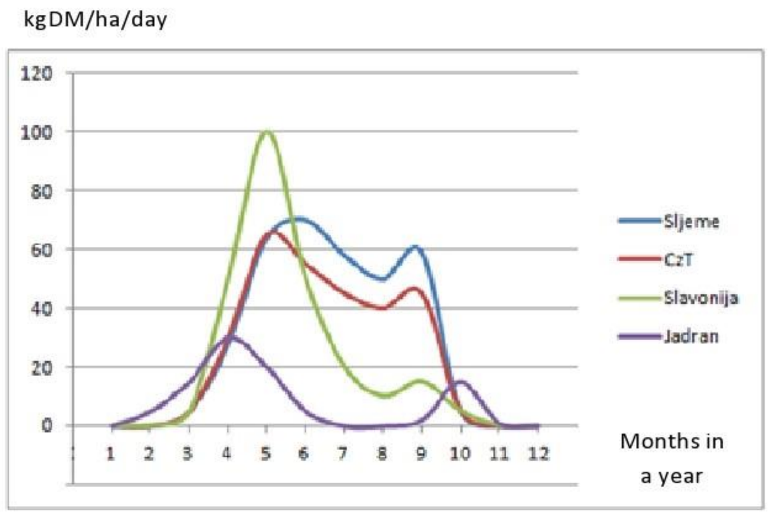



Figure 9. Dynamics of grasslands herbage growth in Croatia. Data for locations Sljeme and CzT (Centar za travnjaštvo, Medvednica) were provided by Krešimir Bošnjak, and for Slavonija and Adriatic Croatia (Jadran) are free estimations of the authors.

## 8.3. Grassland amelioration

Many grasslands suffer either from excessive moisture or from drought. Some kind of drainage, if feasible, can help in the case of a surplus of water, whilst the watering of dry grasslands can rarely be economically viable, mainly because livestock production has much lesser monetary value than vegetables or fruits production. Instead of watering, proper maintenance of grassland can be more appropriate. Namely, dense sward decreases the evaporation and runoff of rain, whilst the bare soil loses more water due to greater runoff and greater evaporation. Organic fertilization (manuring) improves the soil structure, porosity, and water-holding capacity, thus making the grassland more resilient to drought events.

Areas of bare soil often appear in grasslands. They mainly appear because of overgrazing and livestock trampling, but can come because of improper grazing management too, or even because of undergrazing (too low stocking rate) and too low stocking rate (too poor deposition of dung and urine). Bare areas are undesirable because they do not produce forage, they lose more water through runoff and evaporation, they are prone to soil erosion by rain and wind, and leave the space for weeds invasion. Such degraded grasslands can be repaired by improved grazing management, by overseeding, and by reseeding (the last two being called grassland renovation). Improvement of grazing management does not require investments into seed purchase either into soil tillage but may require investments into better fencing of pasture (for inner subdivisions into paddocks). Improvements in grassland are slow in this way. Bare areas and thin stands of the whole grassland can be quicker improved by overseeding, either only the bare areas or the whole pasture. The seeding rate is usually lower here than for the establishment of grass-legume mixes, mainly because this method of renovation keeps the old and productive plants in the renovated pasture. Overseeding can be done by a simple areal spreading of grass and legume seeds (poorer success), or by seeding-in with seeding machines (better success). Reseeding radically changes the grassland because the old sward is usually being destroyed by soil tillage (plowing for example). Soil tillage here usually incorporates greater manure dosages and prepares a fine seed-bed for effective emergence of the seeded grass-legume mix. This is the most radical and most expensive method of grassland renovation, and is rarely recommended. It is somewhat risky because of the uncertainty of the success of the establishment of seeded plants (in cases of drought, poor seedbed preparation, late emergence), and because this method necessary kills the old plants from grassland (due to soil tillage), which would provide a usual forage yield if were not killed. Moreover, this method is not recommended for inclined grasslands due to expected soil erosion. Seeding rates here are similar to the rates for grass-legume mixes establishement on arable land. It should not be forgotten that many perennial grasses achieve their full productivity in the second year and onwards, and that the desirable herbs need at least a few years to inhabit spontaneously the plowed grassland. Grass and legume species for overseeding and reseeding have to be chosen in harmony with the respective soil quality and climate.

## 8.4. Grassland agronomy

Fertilization of grasslands, either by mineral fertilizers or farmyard manure usually boosts their productivity. Mineral N fertilization raises the forage yield, but suppresses the legumes, thus diminishing their share in the sward. Mineral P and K fertilization brings a better balance between plant nutrients and is less detrimental to the botanical composition. Grasslands on deeper soils, with good holding capacity for plant nutrients, can be fertilized with mineral N, P and K rates similar to the rates used on arable soils. Oppositely, grasslands on shallow, stony, inclined, or sandy soils have to be fertilized sparsely to avoid the salt shock in the liquid phase of such soils, and to prevent the losses of plant nutrients by water runoff or volatization. Manuring by spreading the farmyard manure can be expensive due to the excessive volume of this fertilizer and a great amount of transport. However, considering the effects on the sward quality and biodiversity, manuring is the best method for grassland fertilization. It provides well balanced minerals (N, P, K, Ca, Mg and micronutrients) that are being released gradually, and it brings a high-quality organic matter for the improvement of biological and physical properties of grassland soil. Besides by spreading the stored farmyard manure, grasslands can be effectively fertilized with the natural deposition of dung and urine by grazing animals. After the grazing event is over, it is recommended to spread the dung with harrow, to provide for more even distribution and its quicker degradation. Harrowing should not be done when soil is wet to avoid the degradation of soil structure.

Weed control in grasslands is usually done by employing proper grazing and cutting management, since weeds are usually more sensitive to repeated defoliation than perennial grasses and legumes. Clearing can be done by mob grazing with less productive livestock classes (dry sheep or dry cows).

Harrowing of grasslands can help in weed control by pulling-out newly emerged weeds. It can help in the aeration of shallow soil layer thus intensifying the biological activity of soil and release of nutrients that are comprised in the soil organic matter. Harrowing, as mentioned before, helps in spreading the deposited dung, making it evenly distributed over the pasture area. Harrowing helps in “opening” the soil for better reception and emergence of overseeded legumes and grasses when renovating the grassland by the simple aerial spreading of seeds.

Grassland defoliation either by mowing (cutting) or by grazing is a part of grassland agronomy. Defoliation has to be repeated after a proper rest period, and must not be too low (like in deep grazing - to the ground level). The period of stay of livestock on a limited area should not be too long to allow the rest to pasture plants.

## 8.5. Utilization by grazing

Grazing is probably the cheapest way of grassland utilization because jobs of cutting and delivery to livestock are being performed by livestock itself, while the jobs of curing, transportation, ensiling and storage are completely avoided. The aforementioned jobs require a considerable amount of energy, machine work and labor if done by farmers and/or agricultural machinery.

Grazing is also the healthiest way of feeding livestock, if grazed on good quality pastures. Namely, grazing animals are supposed to consume fresh green herbage that is usually of higher quality than preserved forages (hay, silage or haylage) when utilized in analogous developmental stages. Besides better protein content, digestibility and energy density (thanks to avoiding losses during conservation), fresh green herbage is richer in vitamins, pigments and other biologically active compounds. Grazing activity is associated with the natural movement of grazing livestock thus inducing better development of skeleton and muscles, and is associated with more natural behavior (less disorders) than in livestock held in the stalls. Products from grazing livestock (meat and milk) usually contain more A, D and E vitamins because of their presence in fresh green forage, and because of sunbathing of livestock when on pasture. Fatty acid profile found in products from pastured livestock is also much appreciated than from concentrate-fed animals. Grazing livestock is usually healthier than livestock held in the stalls, especially healthier than livestock fed with TMRs rich in concentrates, what decreases the probability of antibiotic residues in products from pastured livestock. Pastured livestock is usually reared without hormones administration, what is a further advantage when compared to intensively grown or fed livestock. Emerging data indicate that when livestock are eating a diverse array of plants on pasture, additional health-promoting phytonutrients (terpenoids, phenols, carotenoids, and anti-oxidants) become concentrated in their meat and milk. Several phytochemicals found in grass-fed meat and milk are in quantities comparable to those found in plant foods known to have anti-inflammatory, anti-carcinogenic, and cardioprotective effects (van Vliet et al., 2021). Because of the many aforementioned benefits of pastured livestock, there has appeared a relatively modern marketing category of livestock products: grass-fed meat and grass-fed milk. Customer preference for such products can be depicted by the fact that grass-fed beef was sold in the retail market in the USA for about double the price than confinement TMR-fed beef in the year 2021 (USDA, 2021).

### 8.5.1. Elements that affect the productivity of grazing livestock

**Total pasture area** (TP) is the area of pasture required to produce the sufficient forage for grazing (i.e. DM consumption) during the grazing season, and can be expressed in ha per head (ha/head) or hectares per livestock unit (ha/LU). TP depends on the whole-season pasture yield (PY, $kg_{DM}$/ha), seasonal pasture consumption (PC) per head ($kg_{DM}$/head) or per livestock unit ($kg_{DM}$/LU), and on utilization rate, which can often be between 50 and 90 %, depending on the grazing efficiency.

**Stocking density** (SD) is a relationship between the number of animals and occupied pasture area at any one time. It can be expressed in the head/ha or LU/ha. High stocking densities are employed in intensive grazing management (because livestock is temporarily concentrated on a certain paddock or a division of pasture), while SDs are low in extensive grazing management (because the livestock is spread through the whole pasture). In older literature stocking density was often referred as stocking rate.

**Allocated pasture area** (AP) is a pasture area allocated to grazing animals at a certain moment and is reciprocal to stocking density. It is expressed in ha/head or ha/LU.

**Stocking rate** (SR) is a relation between the number of animals and the total land area available for forage production. It should not exceed the carrying capacity of farmed land. It is also expressed in the head/ha or LU/ha.

**Period of occupation** (PO) is a period during which the livestock occupies a certain pasture or pasture subdivision (i.e. paddock). Short periods of occupation (of about a few days) are usually employed in intensive grazing management, to enable a short deherbation period and a long rest period for pasture plants.

There is usually required subdivision of total pasture area into subdivisions named paddocks. Long periods of occupation are employed in lax grazing management, when there are available extensive pastoral resources. Period of occupation is usually expressed in days, but can be even shorter in very intensive grazing management.

**Rest period** (RP) is a period during which pasture plants are left undisturbed, with no defoliation to replenish their energy reserves and to build a sufficient forage mass for the subsequent grazing that will take place in the next period of occupation. It is expressed in days. Generally, for optimal pasture yield, the rest periods should be about 30 days, although in spring the rest period can be as short as 15 to 20 days, and in summer it should be longer (30 to 40 days).

**Forage mass** (FM) found on pasture at a certain moment affects the size of the bite of livestock, the need for livestock movement in a search for food, and the quality of ingested forage. It can be expressed either as whole aboveground forage mass or forage mass above a certain height from the ground level (usually above 1.5 cm for sheep and above 4 cm for cattle, since these heights are easily available for biting) per unit area (usually per hectare, $kg_{DM}/ha$ or $t_{DM}/ha$). It is often used for the calculation of the average daily forage allowance per head or livestock unit. In the periods of poor pasture growth (summer or late autumn) or short periods of occupation, it is usually taken as initial forage mass at the moment when livestock enters the pasture or paddock. When livestock enters the fast-growing pasture (in spring) and if the longer period of occupation is intended, it is reasonable to add an expected forage growth during the period of occupation (for the calculation of average daily forage allowance):

$$FM_t\ [kg_{DM}/ha] = FM_i\ [kg_{DM}/ha] + EDG\ [kg_{DM}/ha/day] \times PO\ [days]$$

Where $FM_t$ presents the total forage mass available for consumption during a period of pasture (or paddock) occupation, $FM_i$ presents the initial forage mass at the moment when livestock enters the pasture (or paddock), EDG is expected daily growth of pasture and PO is a period of pasture (or paddock) occupation by livestock.

When measured (cut) from the height of 4 cm above the soil level, forage mass lesser than 500 $kg_{DM}/ha$ is considered poorly available and limits the forage dry matter intake (DMI), mainly because bites are small and animals have to spend their time in a search for forage. To allow for a good DMI and appreciable livestock performance, forage mass should not be lesser than 1000 $kg_{DM}/ha$ (when measured above height of 4 cm above soil level). Based on these values, the **residual forage mass** ($FM_r$) left after grazing session should be somewhere between 1000 and 500 $kg_{DM}/ha$ (above grazing height of 4 cm), depending on the targeted animal productivity.

**Residual forage mass** ($FM_r$) remained after the livestock is removed from pasture (or paddock) affects the productivity of grassland and the productivity of animals. Too short residual forage mass indicates that grassland was utilized almost to the ground, what exhaustes the plants with the consequence of poor regrowth. Too short residual forage mass also implies that animals were undernourished or even starving at the end of the period of occupation, thus adversely affecting the performance of livestock. Oppositely, higher residual forage mass usually enables for faster regrowth of grasses and higher seasonal forage yield of pasture. Residual forage mass of about 1000 $kg_{DM}/ha$ will probably not adversely affect the livestock performance, and will enable for quick grass regrowth and high annual yield, whilst the 500 $kg_{DM}/ha$ is considered poorly available with negative consequences.

**Initial forage mass** ($FM_i$) at the start of grazing session is optimaly between 2000 and 3000 $kg_{DM}/ha$, thus offering a plenty of forage at small area, and enabling for large bites and quick rumen filling.

Though, too big forage mass is usually associated with old and stalky herbage with a considerable share of yellow and dead grass leaves.

The optimal range between maximum and minimum herbage mass (i.e. initial and residual forage mass) during the period of pasture (or paddock) occupation varies with the type of grassland and present plant species, but can be roughly estimated between 2500 and 1000 $kg_{DM}$/ha (when measured above 4 cm). However, on poor-yielding pastures, tresholds for initial and residual forage mass have to be set lower because low-yielding pastures need too much time to reach the previously mentioned values. The same should be when the grazing season approaches its end and grasses come to their winter dormancy. On poor-yielding pastures the expected livestock productivity is lesser than on high-yielding ones because of limited forage availability and consumption.

**Difference between initial forage mass and residual forage mass** ($FM_{i-r}$) represents the forage mass intended for utilization by grazing animals: $FM_{i-r}$ ($kg_{DM}$/ha) = FMi - FMr

**Forage height** (FH) is measured in cm above ground level. For short grasses and legumes (perennial ryegrass, Kentucky bluegrass, red fescue, white clover) it is optimally to start grazing when herbage is 10 to 15 cm tall, whilst for tall grasses and legumes (tall and meadow fescues, cocksfoot, red clover, lucerne) it is optimal to start grazing when they are 20 to 25 cm tall (Leto, 2016). However, cut-type lucerne cultivars, for a good yield and satisfactory persistence, have to rest between grazing events, at least until the height of 35 cm (Berone et al., 2020). According to Leto (2016), the optimal **residual height** for tall grasses and legumes is 10 cm from the ground level, while for the short grasses and legumes it is 5 cm.

Daily **forage allowance** (FA) or average daily forage allowance is a forage that occupied pasture area offers daily to the grazing animals, expressed in $kg_{DM}$/head/day or $kg_{DM}$/LU/day. It can be expressed from the ground level or above the grazing height (above 1.5 cm for sheep and above 4 cm for cattle), what is more practical because it represents the easily available forage. Targeted forage allowances should be somewhat greater than the targeted DMI (about 10 to 30 % greater than DMI). Greater forage allowances usually allow for a greater daily DMI and greater livestock performance, but a poorer utilization rate, while the lower forage allowances do oppositely. When there is a poor forage quality on pasture, two-fold or even greater forage allowances can provide for the selection of better-quality plant parts by livestock, and maintain a good livestock performance. Forage allowance can also be expressed in percentage from the animal body weight (% of BW/day).

**Grazing pressure** (GP) is a relation between the number of grazing animals and forage on offer, and is reciprocal to the forage allowance. It is expressed as head/$kg_{DM}$/day or LU/$kg_{DM}$/day.

**Selective grazing** is a rejection of poor quality plants (weeds for example) and plant parts (hardy stalks for example), while consumption of better quality plants (high quality grasses and legumes) and plant parts (leaves and young aftermath). For good pasture maintenance, selective grazing is undesirable because it allows for the incomplete utilization of available forage and the spread of weeds in pasture. It also exhausts the plants whose young aftermath was too frequently grazed. Too much exhausted plants can dye-off thus leaving the bare soil. Farmers very often employ more or less sophisticated grazing methods to minimize selective grazing, thus achieving the more complete utilization of available forage and maintaining the pasture in a better condition.

Many of the above-presented variables of grazing management are mathematically interdependent, as can be seen from the expressions below. They can be a useful tool for sizing the pastures area and for the development of a grazing plan.

TP (ha/head) = PC ($kg_{DM}$/head) : PY ($kg_{DM}$/ha) : utilization rate

SD [head/ha] = $FM_{i-r}$ [$kg_{DM}$/ha] : FA [$kg_{DM}$/head/day] : PO [days]

AP [ha/head] = 1 : SD [head/ha] = FA [$kg_{DM}$/head/day] × PO [days] : $FM_{i-r}$ [$kg_{DM}$/ha]

PO [days] = FM [$kg_{DM}$/ha] : FA [$kg_{DM}$/head/day] : SD [head/ha]

FA [$kg_{DM}$/head/day] = $FM_{i-r}$ [$kg_{DM}$/ha] : SD [head/ha] : PO [days]

$GP$ [head/kg$_{DM}$/day] = 1 : $FA$ [kg$_{DM}$/head/day] = $SD$ [head/ha] × $PO$ [days] : $FM_{i\text{-}r}$ [kg$_{DM}$/ha]

$FM_{i\text{-}r}$ [kg$_{DM}$/ha] = $SD$ [head/ha] × $FA$ [kg$_{DM}$/head/day] × $PO$ [days]

As can be seen from the formulas above, the allocated pasture area can be adjusted to the number of livestock, to the targeted forage allowance and to the targeted period of occupation, all in accordance with the available forage mass. Manly, there are two pretty constant variables: the number of livestock and the targeted daily forage allowance. By manipulating the allocated pasture area and period of occupation, farmers can adjust their pasture to meet the herd's (or flock's) needs for DMI, in line with the on-pasture present (or available) forage mass.

8.5.2. Grazing methods (synonym *stocking methods*)

Farmers can choose among various simple grazing methods, intermediate ones and sophisticated ones. Simple movements of the herd (or flock) along broad pastures is an ancient method of livestock guidance and grazing, that imitates the natural movement of big herds (flocks) of wild big herbivores. It allows for a short period of stay in a temporarily occupied area, and a long rest period before the return of herd (flock). There is usually no fencing here, but shepherd dogs are required to gather and control the moves of livestock, and to protect the livestock from wild predators. This kind of grazing management is often found in nomadic people, but is also present in the sedentary people of mountainous areas.
When pasture areas are limited, farmers usually chose among the grazing methods described below.

**Continuous grazing** (synonym *continuous stocking*) refers to a (timely) unlimited occupation of the whole particular pasture. Livestock moves freely and is allowed to selectively graze. For this grazing method, a minimum of livestock movement control is employed and a minimum of fencing is required (only outer fences of pasture). Livestock usually occupies a large single pasture during the whole grazing season, so the stocking density is virtually small. However, since the livestock naturally gathers into herds, and naturally moves from the grazed (and dunged and urinated) area to the ungrazed, stocking density is high at each moment on a route that livestock is moving on. Since the livestock herd moves freely, after some time there can appear more visible routes where the livestock have repeatedly grazed young aftermath. Repeated grazing of the young aftermath can lead to thinning of sward and areas of bare soil. Since the forage on-offer is much greater than livestock can consume during the excessive spring growth, a certain part of spring yield senescence and becomes less palatable. Therefore the livestock avoids it, what leads to incomplete utilization of pasture yield. When this method of grazing is employed, there is no means for setting aside a part of excessive spring growth for conservation (for haying or ensiling). This is because the dung is randomly distributed all over the pasture, and the mowed herbage would occasionally fall onto dung and got dirtied. Despite many objections to this grazing method, it is broadly accepted by livestock farmers because of its simplicity. And many researches around the world could not prove that such a grazing method necessarily leads to a poorer pasture or livestock performance. This especially holds true for environments where the grass growth occurs only in a short spring season, like in arid climates of American rangeland.

**Rotational grazing** (synonym *rotational stocking*) refers to a rotational movement of livestock over the pasture subunits called paddocks. Pasture division into paddocks is done by inner fencing. Subdivision is required here, to spacially limit the livestock and force them to thoroughly utilize the available forage on-offer. Thus, it diminishes selective grazing. After the forage on-offer is satisfactorily utilized (consumed), the livestock is being removed to the next paddock. A utilized paddock is left to rest for a required rest period to replenish the energy reserves and build-up sufficient forage mass for the next defoliation (grazing event or haying). Paddocks have to be properly sized to provide enough forage for the targeted average period of occupation. The number of paddocks has to be sufficient to enable the required average rest period and limited occupation period of each paddock. The number of paddocks (NP) in a succession, average rest period (RP), and average period of occupation (PO) are mathematically interdependent:

$PO_{AVG}$ [days] = $RP_{AVG}$ [days] : (NP – 1)

The intensity of rotational grazing management increases with the number of paddocks. Intensive grazing management is characterized by short periods of occupation, while the extensive one is with long periods of occupation (Table 29).

Table 29. The number of paddocks affects the average period of occupation, when the average rest period is about 30 days.

| Number of paddocks (n) | The average period of occupation (days) | Average rest period (days) | The intensity of rotational grazing management |
|---|---|---|---|
| 16 | 2 | 30 | intensive |
| 11 | 3 | 30 | |
| 9 | 4 | 32 | intermediate |
| 6 | 6 | 30 | |
| 4 | 10 | 30 | lax |

Subdivision into paddocks enables the setting aside a part of pasture area during the excessive spring growth for haying or ensiling. Namely, set-aside paddock(s) is (are) excluded from grazing during the excessive spring growth, so the soil is not dunged, and mowed forage will not be dirtied, therefore. Conclusively, the main advantages of rotational grazing over continuous grazing are the provision of rest periods to pasture plants and better utilization efficiency of the forage on offer. Although setting-aside can be an advantage of rotational grazing, it is feasible in continuous grazing too. Namely, a part of the pasture area can be deffered from grazing during the excessive spring growth, and after the first cut is taken, livestock can be allowed to enter the previously deffered area.

**Strip grazing** (synonym *strip stocking*) allocates to the livestock each day a new, ungrazed pasture area, sufficient to provide a targeted daily forage allowance. In addition, livestock is enabled to regraze the pasture area that was grazed a day or two days before. Since the livestock occupies a relatively narrow strip in a forward succession, this way of grazing is named strip grazing. This can be considered more intensive grazing management than rotational one, since the livestock is each day removed (frontally) to the ungrazed area.

Figure 10 visualy presents the three most popular grazing methods in western world (continuous, rotational and strip grazing).

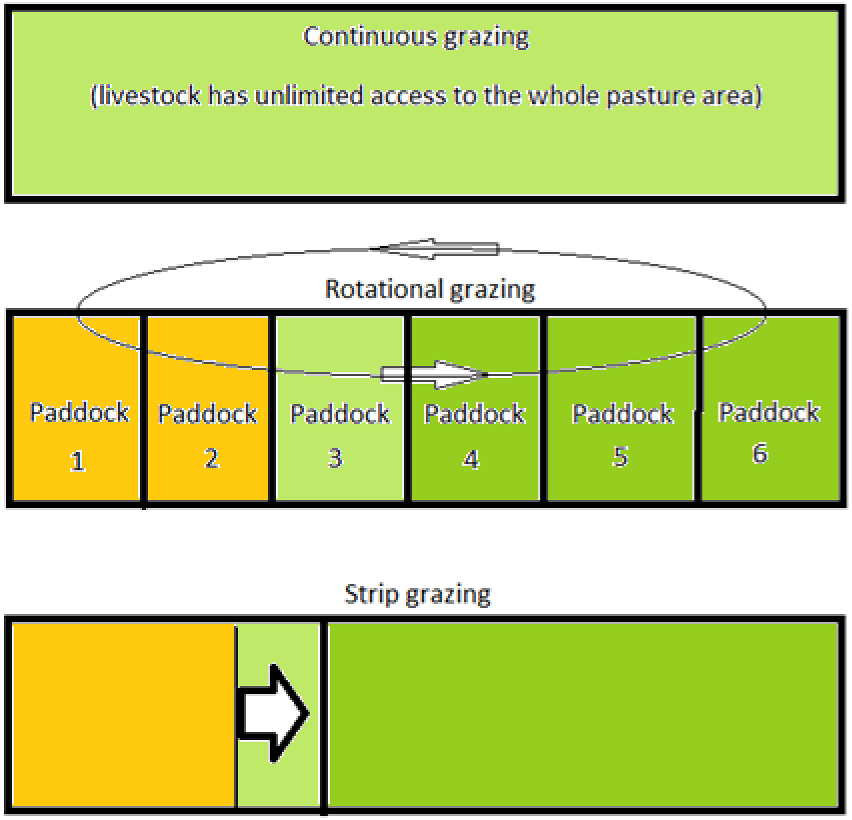



Figure 10. Schematic presentation of the three most popular grazing methods in western world

**Frontal grazing** is intensified variant of strip grazing. It is performed by continuously moving electric wire in front of livestock. It enables the livestock to slowly move forward to the ungrazed area, during the whole grazing session (i.e. during the whole day).

**First-last grazing** is employed when farmers want to provide the most productive livestock classes (milking cows or sheep, fast growing young animals) with the highest quality and quantity of forage, while leaving the residual forage to the less productive classes (dry cows and dry sheep). In the rotational grazing management, each paddock is firstly utilized by highly productive livestock, and after they are removed, less productive livestock enters that paddock to utilize the residual forage.

**Mixed grazing** implies two or more herbivore species graze simultaneously in the same pasture or paddock. This is usually associated with better utilization efficiency of forage on offer (because of different preferences of various livestock) and with better health of grazed animals (because of lesser infestation with specialized parasites).

**Mob grazing** implies grazing with very high stocking density and very high grazing pressure to achieve overgrazing of the targeted area. Most often, the goal of this grazing method is to control the weeds.

In small farms, with only a few animals, controlled grazing can be done by tieing an animal with a rope to a grounded stake or anchor. Animal will graze the available herbage around the grounded stake in a radius of a rope. When the available forage become utilized, animal is moved to ungrazed area by displacement of grouded stake or anchor. This method can be called “grazing around a grounded stake”.

### 8.5.3. Bloat of grazed livestock

Fresh and lush pasture can cause bloat in grazing livestock. Legumes are especially risky when in the vegetative stage. Causes of bloat in ruminants are most often a high concentration of easy degradable plant protein and a high concentration of nitrates in herbage. Among the causes can be unadapted rumen microbiota to fresh green herbage. After the winter period of hay and silage feeding, livestock has to be gradually adapted to fresh herbage on pasture. Traditionally, farmers were letting the livestock on pasture when the available forage was too low to disable the gluttonous gorging. Livestock was supplemented with hay until the fresh herbage become abundantly available. Livestock needs about seven to 10 days for adaptation to fresh herbage from pasture. In this period hay and haylage have to be gradually replaced with pasture. Adapted livestock is pretty safe unless become hungry and gluttonously gorge the fresh and lush pasture rich in legumes or rich in nitrates (after mineral N fertilization for example). When conducting rotational grazing, the manager should always ensure that livestock enters a new paddock satiated and in the afternoon. Afternoon entrance is important because nitrates uptaken during the night are being build-in into plant protein thus diminishing the bloat risk. Satiency is important to avoid gluttonously gorging. Leaving the greater residual forage ensures that livestock was not hungry at the moment of removal to a new paddock. Pastures rich in legumes (more than 40 % in DM yield, except birdsfoot trefoil and esparsette) are riskier than pastures rich in grasses (more than 60 %) or herbs. Many herbs are bloat preventers. All aforementioned preventive measures are highly recommended when livestock is grazed on legume-rich pastures.

### 8.5.4. Pasture equipment

Pastures have to be fenced from outside to prevent the loss of livestock and wild predators' attack. Inner fencing is required for rotational, strip and frontal grazing. Fencing can be done with a fix (mostly wooden) or mobile (mostly tensile electric wire) fences. Gates are required for the controlled entrance and removal of livestock. Paths have to connect stalls and pastures. Livestock needs a shadow during summer, either under shelter or under trees (this natural is the better one). Waterholes are necessary for providing the livestock with drinking water. Shepherd dogs are not the equipment but can be very useful for gathering, guiding and protecting livestock. There are special dog breeds bred for protecting the livestock from predators, and special for gathering and guiding the livestock.

## 8.6. Utilization by cutting for hay, haylage and silage

First spring growth of grasslands should be cut from the end of stem elongation (flag leaf stage) till the fool bloom of dominant grass species. Later cutting is associated with poorer quality of hay and poorer aftermath yield. Early cutting provides better hay quality (if no rainfall during curing the hay) and faster regrowth of the first and second aftermath. Cutting height should be about 4 to 5 cm above ground level to enable for a quick regrowth. Aftermaths can be taken when grasslands accumulate enough forage to be reasonable for cutting and haying operations. Regrowth of aftermath can be 40 or more days, depending on the rainfall during summer (more rainfall, the quicker regrowth). Very often only the first spring growth is taken for haymaking, whilst the regrowths are grazed.

# 9. CONSERVATION OF FORAGES

## 9.1. Haymaking

Hay is a dried (cured) form of forage that is prevented from spoilage by its dryness. Namely, the lack of available water prevents the microorganisms to spoil such a forage. Haymaking or haying implies a series of operations needed for hay production. The first operation is mowing or cutting a standing forage crop. It can be performed by mowers driven by tractors or pulled by horses, or by hand scythe on small farms. Mowers can be of a scissors-type or rotary-type. Rotary-type mowers leave the cut forage in swaths, and therefore raking is needed to spread the herbage for quicker drying. When forage is dried to about 15 % of moisture it can be considered as hay. Hay has to be collected into windthrows to enable for efficient picking-up with balers. Balers pick-up the hay and press it into round or square bales. Bales can be low- or high-pressure ones. Deposited bales have to be transported to the sheltered storage as soon as possible. Traditionally, hand-scythe cut hay was stored in haystacks. Speed is much appreciated in drying and haymaking to decrease the probability of wetting the hay by the incidence of rain. Mowers equipped with pressing rollers are longitudinally breaking the stems of forages, thus speeding-up the loss of water during hay curing. Half-dried hay can be baled and subsequently artificially dried in driers. In mountainous regions, farmers very often dry their hay on installations that resemble to ladder with a narrow roof. This prevents the damage from rain during hay curing.

## 9.2. Ensiling

Silage is a form of forage conserved by acidic fermentation in anaerobic conditions. It is moist forage, with 30 to 40 % of dry matter content. Anaerobic conditions and acidification to the very low pH (about pH 4) prevent the spoiling caused by microbiological activity. Lactic-acid and acetic-acid bacteria produce organic acids from the sugars present in forages, thus naturally acidifying the herbage. Technically, forages rich in sugars (whole-crop maize, sorghum, sudangrass, and ryegrasses) have to be cut and chopped by silage harvesters, and then transported to the horizontal silo. If the DM content in herbage is lower than 30 %, herbage has to be dried in a field before ensiling, in order to enable a desirebale fermentation and conservation. Along with filling the silo with herbages, herbages are being pressed by treading tractor. After the silo is completely filled, the pressed herbage has to be tightly covered to prevent the entrance of air into it. This way stored herbage undergoes an acidic fermentation that lasts for about 40 days. After the fermentation is completed, the silo can be opened and silage can be fed to the livestock. Silage has to be gradually introduced to the herbiovore diet in order to allow for their adaptation to acidic forage.

## 9.3. Haylage production

Haylage is a semi-dry (or semi-moist) and fermented forage. Only fine-stemmed forages can be stored as haylage because hard- and thick-stemmed forages are impossible to press airtightly at such a low moisture content (about 50 %). Haylage is more often produced from forages rich in protein and poor in sugars because acidic bacteria cannot produce enough acids for reliable conservation there. Therefore, another mechanism of microorganisms suppression is employed: the decreased water availability, or greater dryness than in silage. This product is called haylage because it is an intermediary between hay and silage. Technically, it is being produced by ensiling the half-dried herbage. Production starts as haymaking and when the mowed herbage reaches DM content between 40 and 60 %, it is being chopped and transported to the horizontal silo for ensiling, or is being pressed into high-pressure bales and wrapped with plastic folia. The addition of lactic-acid bacteria in chopping can speed up the acidification and improve the quality of haylage. Livestock generally prefer haylage over silage because it is not so acidic as silage is.

## 10. FARMYARD MANURE PRODUCTION AND UTILIZATION

Farmyard manure (FYM) is an important resource for improving soil fertility and raising forage yields. Nutrients uptaken by forage crops and ingested by livestock are being largely recirculated to the farm's land by application of farmyard manure. It can be practical to know how to estimate the annual FYM production and to know the average or expected minerals contained in it.

Mihalić (1985) has presented a very old formula for estimation of FYM dry matter production:

FYM [kg/year] = consumed dry matter [kg/year] : 2 + bedding dry matter [kg/year]

After a half-year fermentation of stored FYM, there is expected a loss of ¼ of the initial FYM DM.

Livestock unit (500 kg of BW) with daily DMI of about 3 % of BW that uses about 4 kg of straw for bedding produces about 4.25 $t_{DM}$/LU/year of FYM DM. Since the fermented FYM contains about 25 % of DM, the as-it-is production of FYM can be estimated at about 13 t/LU/year.

Since the FYM contains about 0.6 % of N, 0.3 % of $P_2O_5$ and 0.7 % of $K_2O$, annual production of N, P and K in FYM can be estimated to be 77 kg/LU/year of N, 38 kg/LU/year of $P_2O_5$ and 89 kg/LU/year of $K_2O$.

Since the FYM is a limited resource, its application can be prioritized for the high-yielding crops that require abundant fertilization (forage maize for example).

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