Review Article

All About Fodder Beet (*Beta vulgaris* subsp. *Crassa* L.) As a Source of Forage in the World and Syria

Entessar Al-Jbawi*(1)

(1). Sugar Beet Research Department, Crops Research Administration, General Commission for Scientific Agricultural Research (GCSAR), Damascus, Syria. (*Corresponding author: dr.entessara@gmail.com or dr.entessara@gcsar.gov.sy).

Received: 01/08/2020 Accepted: 11/09/2020

Abstract

Forage crops are very important for livestock production in the world and in Syria, and the potential for fodder beet is becoming more widely recognized. Improved plant genetics, herbicides and agronomy techniques are providing the impetus for a shift toward this exciting crop. This article contains information relating to classification, taxonomy and description of fodder beet; and the steps required to help grow a successful crop, starting from field selection through harvest to storage. Fodder beet is one of the highest yielding forage options available to farmers. Its full potential will only be achieved by good husbandry.

Key words: Fodder beet, Classifications, Agricultural practices, Pasture, Storage.

Introduction:

There is an interest among farmers in many countries to grow forage and fodder crops to meet their own livestock production needs, and recently attention has grown to the cultivation of this crop in Syria (Al Jbawi *et al*., 2019). Fodder beet is a high yield potential than any other arable fodder crops (Anonymous, 2006). The main use of fodder beet is for feeding ruminants, though it can also be fed to pigs (Henry, 2010; Rees and Westmacott, 1956). The above and below growth parts (leaves and roots) are used to feed the animals but, the main fodder is tuberous roots (Ibrahim, 2005; El-Sarag, 2013).

The high sugar content makes fodder beet palatable and a valuable energy source (Draycott and Christenson, 2003).

Animal production in Syria depends mainly on natural range which is affected by rain fluctuations and low-quality grasses, especially during periods of forage shortage like late winter and early summer. This necessitates the introduction of irrigated forage crops in the irrigated schemes and in farms around cities where farmers raise cattle (Al Jbawi *et al*., 2019).

Forage is defined as feedstuff that animals search for and consume, and commonly refers to the non-reproductive portions of plants, while fodder refers to all plant portions which are harvested, stored, and fed to animals (Barnes *et al*., 1995). Successful local production of forage and fodder crops requires a review of past practices and the latest research on crop varieties as it applies to specific growing conditions. Historically, livestock production relied on a large diversity of crops to sustain animals year-round, including vegetable root crops such as fodder beets, turnips, rutabagas, carrots, and

sugar beets (Delwiche, 1924). Vegetable fodder crops were produced in significant amounts in the maritime Pacific Northwest until 1935, but by 1955 production was limited to a few acres (Schoth, 1957). As the scale of livestock production increased and intensified, livestock and fodder production became separate operations, each located in regions that were most conducive to optimizing production and minimizing costs.

New cropping systems arose to best fit large-scale livestock production needs.

Now, new varieties of vegetable forage and fodder crops are available that promise larger yields, better storability, and greater flexibility in use. These new varieties offer the potential for livestock producers to grow an increasing amount of their own livestock feed that is well-adapted to the growing environment, affordable to produce, and a good source of livestock nutrition.

Classification:

Family, genus, and species: Amaranthaceae *Beta vulgaris* L. The fodder beet belongs to the family Amaranthaceae (formerly Chenopodiaceae), which includes no less than 105 genera divided into 1,400 species, and whose members are herbaceous dicotyledonous plants (Watson and Dallwitz, 1992). In the literature, it has often been called mangel, mangold, or wurzel instead of fodder beet. Other economically important cultivated groups are the sugar beets, table beets, and leaf beets (e.g., Swiss chards); these too all belong to the species Beta vulgaris (Al JBawi, 2012). The table beets and Swiss chards are mainly used as vegetables, the sugar beets as a source of sucrose, and fodder beets as cattle feed (Al JBawi, 2012).

Common names: Fodder beet root, cattle beet, forage beet, field beet, mangold, mangold-wurzel, mangel, mangelwurzel, mangel beet [English]; betterave fourragère [French]; voederbiet [Dutch]; Futterrübe [German]; چغندر گاوی [Persian]; Свёкла кормовая [Russian].

Currently available varieties: Yellow Cylindrical (Figure 1), Yellow Intermediate Mangel/Beet, Golden Eckendorf Mangel/Beet, Robbos (aka Maestro) Red (Figure 2), Long Red Mangel, also called Colossal Long Red Mangel and Mammoth Long Red Mangel (Figure 3).

Figure 1. Yellow Cylindrical.

Figure 2. Robbos (aka Maestro) Red.

Figure 3. Mammoth Long Red Mangel.

Taxonomic information:

The classification of both wild and cultivated forms of *Beta vulgaris* is confusing. It is generally accepted that all cultivated beets belong to the *Beta vulgaris* subsp. *vulgaris* subspecies. This subspecies is divided into the following groups: Root beets *Crassa* (fodder beets), *Altissima* (sugar beets) and *Conditiva* (garden beets), and leaf beets *Flavescens* (Swiss chard) and *Cicla* (spinach beets) (Hopp and Oyen, 2004; Al Jbawi, 2012).

In the UK, the name "fodder beet" refers to varieties with smaller roots and high DM content, while types with broader roots that sit high in the soil are called "mangels" or "mangolds". In Germany, "mangolds" refers to white varieties of leaf beets (Henry, 2010).

Description:

Fodder beet (*Beta vulgaris* subsp. *vulgaris* L.) is a biennial plant grown for its fleshy and swollen root. The size, shape and colour of the root are extremely variable and depend on the variety (Al Jbawi, 2012). Roots from fodder varieties tend to be less deeply buried (up to 2/3 above ground) than those of sugar and intermediate fodder-sugar varieties (ADBFM, 2009). The vegetative part develops mainly during the first year of growth. The dark green, heart-shaped leaves are borne in a rosette, lying horizontally to catch as much light as possible (Al Jbawi, 2012). After the first year, if the root is not harvested and after exposure to cold, the rosette turns into a 50-80 cm tall flower stalk that bears small, green and bisexual flowers without petals (Henry, 2010). Fodder beet crops that are intended for fodder (rather than for seed production) are cultivated as annual crops and the roots must be harvested before winter since they do not withstand frost (ADBFM, 2009).

In Northern Europe, fodder beet has been used as fodder since the Middle Ages. It became a major winter feed for cattle in the 1800s. Traditional fodder beet had multigerm seeds resulting in clusters of 2 or 3 plants, which required manual separation (thinning) of the young plants. This labour-intensive aspect of fodder beet cropping led to its decline after World War II and fodder beets were replaced by maize in ruminant diets. The development of monogerm varieties in the 1970s allowed full mechanization and higher yields, resulting in a renewed interest in fodder beet (Henry, 2010).

Background:

Fodder beet originated in the Middle East and was being used as cattle feed in ancient Greece in 500 BC (Henry, 2010). It was grown as a root crop in Germany and Italy as early as the sixteenth century. It is world-wide in temperate zones up to 55o N (WWW.biolaie.uni-hambura.de, 2006). Beta vulgaris L. ssp. maritima is regarded as the parent species of the cultivated beets (fodder beet, sugar beet, beetroot, yellow beet, Swiss chard) (OECD, 2001; Al Jbawi, 2012).

It is thought to have originated from a cross between the red and white garden beet (Wilson, 1859). The crop spread to Europe and was cultivated throughout Europe from at least the mid-1500s primarily as livestock fodder but were also eaten by people, especially during food shortages. According to John Wrightson (1889), who wrote about fallow and fodder crops, there were about 2.3 million acres of turnips, rutabagas, and fodder beets cultivated in Great Britain during the late 1800s. It was introduced also, into the USA in 1800 and is now cultivated worldwide in the cooler climates (Northern America, New Zealand and at higher altitudes (above 600-1000 m) in the tropics (Oyen, 2004; OECD, 2001). Fodder beets remained a popular crop for livestock until the early 1900s due to their drought tolerance, excellent root-keeping qualities, high sugar content, good leaf fodder characteristics, high nutritive value, and large yields per acre compared to other forage crops.

Fodder beets are considered more drought-tolerant than other root crops, and less sensitive to weather variations than turnips and rutabagas (Halligan, 1911; Wrightson, 1889). Fodder beets are well-adapted to cool moist climates and so were seen as a good alternative to grains in climates where grain or silage yields were uncertain due to seasonal weather variations (Halligan, 1911). For farmers who were raising just a few animals, it was often considered more economical to cultivate fodder beets than to build a silo for grain or silage storage (Gullickson, 1943).

By the late 1800s in the United States, fodder beets were primarily cultivated on the East Coast where land prices were comparatively high. In the Corn Belt where land was cheaper, grain silage was more economical to produce for livestock feed (Smith, 1905). Although fodder beets yielded twice as much as corn per acre on a fresh weight basis, on a dry weight basis, fodder beet yield was only 75% that of corn (Smith, 1905; Halligan, 1911). A major barrier to

fodder beet production was the hand labor needed for harvest. As cereal grains and livestock became increasingly cost-effective to produce due to technology improvements in transportation systems and storage, lack of production mechanization for harvesting root fodder crops resulted in a dramatic decline in use of non-grain livestock feeds in the United States and Europe (Halligan, 1911). As economic conditions drive up the cost of grain feed, it is worthwhile for livestock producers to again consider alternative fodder crops such as vegetable roots. With modern cultivation and harvest implement, the need for hand labor is greatly reduced. Modern fertility management and irrigation practices continue to increase yields compared to those reported in the most current variety trials in the United States which were conducted almost 100 years ago.

In Europe, cultivated forms of Beta (leaf beet, garden beet, fodder and sugar beet) are grown on more than 5.6 million ha, to which can be added approximately 550,000 ha in North America; 600.000-670.000 ha in China (with promising production and potential for sugar beet); and a number of smaller areas in Chile, Egypt, Iran, India, Japan, Morocco, Tunisia and Syria (Frese *et al*., 2001).

France was the main producer of fodder beets (13,000 ha) followed by the United Kingdom (10,000 ha) and Belarus (8,000-10,000 ha) (Henry, 2010).

Breeding efforts are focused on the sugarbeet crop, while leaf, garden and fodder beet breeding are of regional importance only (Frese *et al*., 2001).

Fodder beet as livestock fodder:

Al Jbawi *et al*., (2018) estimated the protein content in fodder beet roots, which accounted 13% while it was 8% in shoots. Bath *et al*., (1980) evaluated a number of alternative feed sources for livestock, including fodder beets. They found that fodder beet protein content was at 11.3% for roots and 17.0% for shoots.

Historical references (Shepard, 1918) calculated the average closer to 1%. This disparity might be attributed to more effective production practices (i.e., soil fertility) and modern fodder beet varieties. The digestible energy of fodder beets is estimated at 0.16 and 1.60 Mcal/lb as-fed or moisture-free, respectively (Ensminger and Olentine, 1980). Due to their high protein concentration, sugar beet pulp and by-products are commonly fed to livestock as a concentrated energy source.

The dry matter of fodder beets is estimated at 11% (Ensminger and Olentine, 1980). Root vegetables in general are low in fat (less than 1%), have a crude fiber content of 7.5–11.4%, ash content of 9.7–19.2%, total digestible nutrient content of 79.2–60.7% (root and shoot, respectively) (Bath *et al*., 1980), and almost no starch, as the carbohydrates are present in sugar form (Shepard, 1918).

It is the sugar content of fodder beets that makes them palatable to livestock. However, fodder beets do not form a complete diet (act more like a concentrate), and so should be supplemented with a high protein fodder such as alfalfa or clover hay. If fodder beets are fed with grass hay, it is necessary to supplement the feed ration with a high protein additive such as bran or oil meal.

According to multiple historic records (Gullickson, 1943; Bull, 1916; Smith, 1905; Wrightson, 1889), fodder beets are palatable to cattle, hogs, sheep, horses, and poultry, and were used extensively to fatten cows and hogs. However, all root vegetable crops have laxative properties, so it is important to control the amount given to livestock or they will develop scouring (diarrhea as a result of intestinal infection). In sheep, large quantities of fodder beets can cause renal and urinary calculi (kidney stones). Fodder beets were rarely fed to horses, though this appears to be due to cultural reasons rather than scientific ones (Gullickson, 1943; Bull, 1916; Smith, 1905; Wrightson, 1889). When fed in proper amounts, fodder beets maintain healthy livestock digestive systems, promote growth in young stock, and stimulate milk production without imparting flavor in milk (Bull, 1916; Niazi *et al*., 2000).

Feeding rate:

Beet should be chopped as this greatly increases intakes, this is most important for younger cattle and for sheep (Niazi *et al*., 2000). Historic records show that milk and beef cattle were fed up to 30 pounds of fodder beets per day. Smith (1905) observed that adding 10 pounds of fodder beets to other fodder effectively fattened steer. The general recommendation was to slice or shred the fodder beets to prevent animals from choking on large pieces, and mix with green fodder or grain for feeding (Smith, 1905; Gullickson, 1943).

Wrightson (1889) suggested feeding horses 2–3 roots per day if they are eating straw rather than hay. According to Card and Henderson (1933), feeding whole fodder beets to poultry can prevent aggression and cannibalism among the flock.

Varieties:

Fodder beets occur in four different shapes (flat globe, globe, spindle, or cylinder; Figure 4) and three colors (yellow, orange, or red; Figures 1, 2 and 3). Though there are also white and purple fodder beets, these types are not commonly grown and yield appears to have been very low.

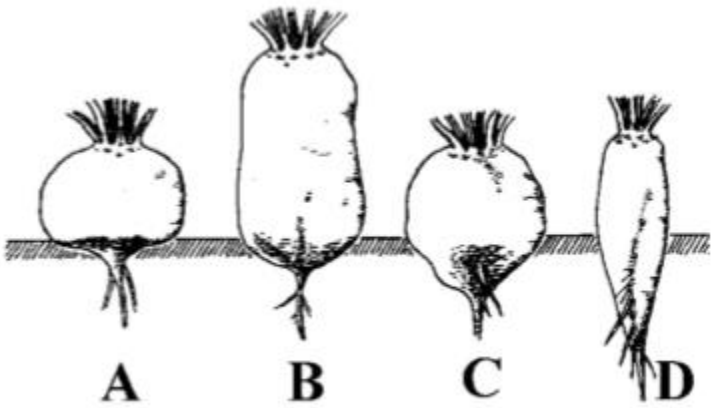

Figure (4. A) Flat Globe; B) Cylinder (Yellow Tankard, Golden Tankard); C) Globe (Yellow, Orange, and Red Globe); and D) Spindle (Long Orange and Red) (Heuze *et al*., 2015).

Yellow Tankard or Golden Tankard was the most popular fodder beet variety throughout England in the late 1800s and was prized for its consistent cylindrical form that narrowed at both ends. A hardy variety suitable for colder northern climates and heavier soils, it was generally considered more drought-tolerant than Long Red (Wickson, 1897). Seeding density in the row is heavier than for other varieties.

Long Orange is very similar in growth habit to Long Red (see below), but was generally considered hardier. Long Red was the highest yielding variety and so was preferred by beef and dairy producers. It requires good soil due to its deep rooting potential, and tends to break if pulled without being first loosened or undercut.

Yellow Globe is shaped like a rutabaga but has lower water content than other fodder beets. It is well-suited to sandy or gravelly soils, but does best if additional organic matter is added.

Orange Globe was the most extensively cultivated fodder beet variety in England in the mid-1800s. The root has an orange skin color but the flesh is yellow to white. It is easier to pull than Long Red varieties.

Red Globe is generally the least productive variety but is better suited for poor, shallow soils.

In Syria, the French company Florimond Desprez has provided a continual supply of new material for General Commission for Scientific Agricultural Research (GCSAR) to evaluate every year in the search for varieties suitable to Syria systems since 2009 i.e. Vermon, Jamon, Splendids, Starmon, Lipari, Varians, Tarine and Caribo and one from SES VNADERHAVE company (SV four 16). Figure (5) shows the colour and the shape of the studied fodder beet varieties at Hama Agricultural Research Station, GCSAR in 2019 season.

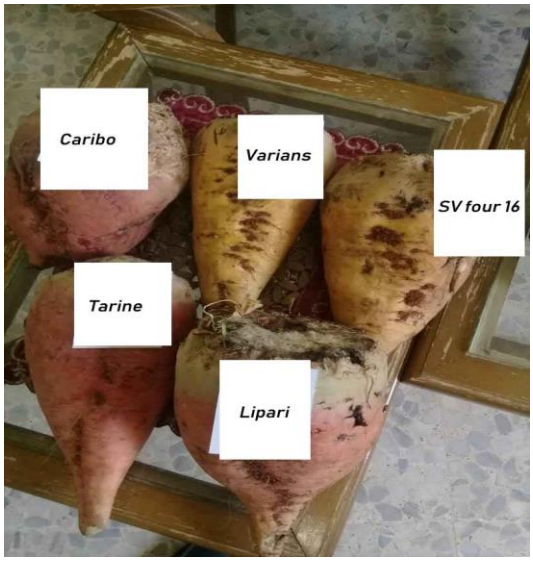

Figure 5. Fodder beet varieties at GCSAR, Hama, Syria.

Types of fodder beet depending on their Dry Matter DM:

Recent research suggests high dry matter (DM) yields of 19–35 t DM/ha (Chakwizira *et al*., 2012; Matthew *et al*., 2011) are attainable in New Zealand. These DM yields are higher than the 10–15 t DM/ha for the traditional winter crops, e.g., kale and swedes (Chakwizira *et al*., 2011; Gower *et al*., 2006; Wilson *et al*., 2006).

ADBFM, (2009) and Limagrain, (2011) defined three types of fodder beet varieties depending on their DM content: fodder (less than 12% DM), fodder-sugar (12-16% DM) and sugar-fodder (16-20% DM).

As a rule, beet varieties are only accepted as sugar beet if the DM is higher than 20% and if the beet is white (Højland and Pedersen, 1994 cited by OECD, 2001).

But some references (Fodder beet guide, 2018) mentioned four types of fodder beet depending on bulb dry matter (DM) % as follow:

1-Low Bulb DM % Fodder Beet:

Fodder beet with low bulb DM % tend to grow more out of the ground (50% of bulb above ground), making them easy to feed in-situ (grazed in the paddock). This type is suitable for all stock classes, though careful yield estimation is important as eye estimates will naturally be drawn to the large bulbs, and the total dry matter yield can be deceptive.

2-Medium and High Bulb DM % Fodder Beet:

Medium and high bulb DM % fodder beet often have a higher yield potential and have bulbs that sit lower in the ground than lower DM types. These are suitable for grazing in-situ, and some are able to be mechanically lifted depending on variety and sowing rate used.

3-Lifting Varieties:

Varieties suitable for mechanical lifting generally have a low and uniform soil tare (the amount of soil attached to the bulb root once lifted). Sowing rate can be increased and used to manipulate the uniformity and bulb characteristics.

4-Sugar Beet:

Sugar beet has high bulb DM % (often above 20%), with a very low soil tare. Sugar beet usually needs to be mechanically lifted and ideally chopped or chipped prior to feeding to animals.

Factors that Influence Dry Matter Percentage:

1-Cultivar selection: Low, medium and high dry matter values are indicative averages only and can range widely.

2-Bulb size: Bulb size is influenced by many factors and generally, as bulb fresh weight increases, DM % decreases.

3-Climate: Where fodder beet is grown in dry environments, the bulbs tend be smaller in physical size and compensate by being higher in dry matter percentage. Measuring fodder beet after wet weather or irrigation will often see a lower DM % being reported
than the same crop measured after a period of dry or settled weather.

4-Paddock variation: Difference in DM % can be caused by soil preparation, soil fertility and soil type all interacting with cultivar choice.

5-Sowing date: This will affect bulb DM % due to maturity and crop size. Yield is highly influenced by growing degree days.

6-Sowing rate: Influences how the crop will grow above ground. A higher sowing rate will result in more bulbs in the row which increases inter-plant competition, leading to smaller bulbs with high DM %.

7-Drymatter sampling methods: Influenced by how long before they are analysed, how many, and how much mud or dirt are on the sample. Use snaplock bags and combine 20 bulb portions.

8-Fertility, soil types and soil preparation: Differences in free-draining vs high water holding capacity soils will affect DM %. An even, consolidated seed bed when sowing is vital.

Field Selection:

Field selection is very important for fodder beet. The crop prefers light sandy to medium clay loam, free draining soil and peats. It is more suited to alkaline soils and does not perform well in acid soils, so the pH will need to be corrected early if there is a known issue and ideally over the preceding 12 months prior to the crop being sown. Soil test the autumn prior to sowing with a 100mm probe to check that the pH is within 6.0 – 6.2. Anything below 5.7 will require liming. Any known issues with nematodes will also need to be addressed, for example by using cover crops. In addition, cover crops will also help improve the soil structure and aid drainage, thereby improving the growing conditions for the beet crop.

Avoid planting a fodder beet crop on poor fields which have a low nutrient status and a high weed burden. Also, check the field history with regard to herbicide use as seedling beet can be susceptible to residual chemicals such as: Aminopyralid (Forefront), Picloram (Tordon) and oxyfluren (Titan, Rival). If following a cereal avoid fields that have a history of Chlorsulfuron (Glean). Similarly, if following a maize or millet crop avoid fields that have a history of Atrazine. It is best if the prior crop has had no post emergent herbicides other than Clopyralid (Lontrel).

If these chemicals have been used and the fodder beet is planted the plants will often emerge more slowly and be discoloured red or brown instead of bright green, and disfigured, curling or crinkling of the leaves, and consequently the crop yield will be significantly reduced.

It is generally best to plant fodder beet after pasture or cereals, especially for the grower's first year of beet production, as the ground will generally prepare well and there are usually fewer weeds to contend with.

Never double crop fodder beet as this will result in significant problems in regards to specific beet diseases and pests. Always use another species as a break crop between beet crops, for at least 2-3 years.

Seedbed preparation:

For strong root production, fodder beets require a fine, deeply plowed, well-drained soil free of clumps or rocks. Prepare the soil for planting as early as possible (Halligan, 1911; Malden, 1891; Wrightson, 1889).

Use light spring tillage, 1–2 inches deep, to prepare a firm level seedbed where good soil-to-seed contact will improve germination (Cattanach *et al*., 1991). In areas where wind erosion is an issue, prepare the field in the fall and plant a fall cover crop that can be mowed or killed in the spring (Kurp *et al*., 2001).

Always focus on optimizing moisture retention in the seed bed especially to the depth where the seed is placed. In most areas a period of moisture builds up will be required to conserve moisture (fallow period). This can be achieved using a chemical fallow, for example spraying out with glyphosate early and again before cultivation. Do not combine Tribenuron methyl or Thifensulfuron methyl with your knock down glyphosate as this will affect seed-ling emergence and can damage seedling plants. If you have multiple weeds in your field other than grass weeds add clopyralid to your glyphosate.

These knock down sprays are crucial for removing as many weeds as possible prior to the crop being planted. Add an insecticide if there is a population of pests present and always add an organo silicone penetrant to aid in knock down and always use an appropriate wetting agent or penetrant to add to the knock down based on weeds present.

Weed control is vital for establishing beets and a poorly prepared seed bed will affect seedling emergence and subsequent herbicide timing.

It is crucial to monitor your field as growing conditions can change leading up to the sowing season. Conditions are rarely uniform across an entire field which is why thorough seed bed preparation is essential for even germination.

Sowing:

Precision sowing of fodder beet is recommended and there are precision drills available to sow the crop. Fodder beet crops sown with conventional drills will have a lot more inter plant competition and non-uniform beets.

Sowing time depends on climate and location but it is generally from early to late spring (after the last frosts) in Netherland, from early April to late May in Ireland, in Syria sowing there are three sowing dates i.e., autumn date which started from mid of October to mid of November, winter date which started from mid of February to mid of March and summer date which started from mid of July to mid of August (Al JBawi *et al*., 2015; Al JBawi *et al*., 2019) . Fodder beet requires at least five days of 10°C or higher before planting. Take into account evening soil temperatures as well as low night temperatures can greatly reduce your germination and subsequent seedling emergence.

To promote rapid establishment seed should be sown to a depth of 1.5–2.0 cm. Drill to lower depths in drier, warmer seed beds. If the seed bed is too loose the seed can often be drilled too deep, even if the depth control is set correctly on the drill, this can affect the evenness and timing of emergence. With precision drills, sowing speed needs to be slow, 4–5 km/hour, to ensure correct seed placement. For good seed to soil contact ensure adequate tension adjustment on the drill's press wheels. It is sometimes necessary to follow drilling with another roll to help even up the seed bed and to conserve moisture.

Sowing Rate:

In Netherland one full box per hectare (100,000 seeds per box) was sown when using a precision drill, at a row spacing of 40–50 cm to achieve the desired plant density. If seed is sown using a conventional drill then a higher seeding rate is typically needed to reduce gaps within the crop (120,000 seeds). If using conventional equipment then the drill should be a sponge feeding type, to minimize the risk of seed being crushed. In Ireland the row spacing is 60 cm, and 20 cm between plants in each row, this gives 70,000 plants per ha. In Syria the suitable row spacing is 60 cm, and 30 cm between plant which gives 60.000 plant per ha (Al Jbawi et al., 2014). Figure 6 shows the plant distances of fodder beet in the trials.

Figure 6. Fodder beet plant distances at Hama Agricultural Research Center, Hama, Syria.

Soil fertility:

Growth characters and yield and or yield attributes of fodder beet responded positively to the fertilization with NPK fertilizers (Abd Allah and Yassen, 2008; Šrek *et al*., 2010).

Prior to applying fertilizer, collect a representative soil sample from the field and send to a soil lab for analysis.

A soil pH range of 6.0 to 8.0 is needed; if the soil tests lower than pH 6.0, apply lime to reach a soil with pH 7.0, because fodder beet is susceptible to acid soils that cause physiological yellowing.

Fertilizer is generally applied prior to seeding to reduce risk of contact in the seed furrow.

Nitrogen is often the most limiting factor in crop production. Hence, application of fertilizer nitrogen results in higher biomass yield (Blumenthal *et al*., 2008). Khogali *et al*., (2011) studied the addition of different levels of N (0, 40, 80 and 120 Kg N/ha) on the productivity of fodder beet in Sudan, and it was broadcast once before the third irrigation (11 days from planting). they found nitrogen fertilization improved yield of fodder beet, and had significant positive effects on root fresh weight, shoot dry weight, and root dry weight, green and dry fodder yields. Mostly, the highest yield and yield components were associated with 80 kg N/ha.

In Netherland nitrogen (N) depends on the levels of available soil N reserves, and beet may require between 100–150 kg N/ha as split applications (Fodder beet guide, 2008).

Potassium plays a vital role in: photosynthesis, translocation of photosynthates, protein synthesis, control of ionic balance, regulation of plant stomata and water use, activation of plant enzymes and, many other processes (Marschner, 1995; Reddya *et al*., 2004). Al Jbawi *et al*., (2018) found that the best potassium level that achieved the highest productivity properties was 120 kg K/ha). In Netherland, the proper potassium (K) application was typically, 75–200 kg K/ha which is adequate in grazing systems (Fodder beet guide, 2008).

Phosphorus is a major element in plant nutrition that is most important component of nucleic acids and lipids and is important in the production and transport of sugars in sugar beet plant. Phosphorus is effectiveness in sugar beet early root development (Kharchenko, 1983). It is a critical macro nutrient required for numerous functions in plant, including energy generation, nucleic acid synthesis, photosynthesis, glycolysis, respiration, carbohydrate metabolism and nitrogen fixation (Abel *et al*.,

2002; Vance *et al*., 2003). In Netherland phosphorus (P) was typically added at 50–70 kg P/ha pre planting, and Sulphur (S) was preferred to be added if the S levels are less than 7 mg/kg then apply 25 kg S/ha. In terms of Calcium (Ca), fodder beet does not use a large amount of Ca. However, this is important for correcting pH, so ensure lime or dolomite is applied pre crop where required. Also, regarding Magnesium (Mg), if the Mg levels are less than 1.3 mg/kg then apply 50–200 kg Mg/ha of Magnesium oxide broadcast prior to cultivation. Besides beet will not grow rapidly without an adequate supply of Sodium Na. Na and K can substitute each other in the plant. If both Na and K are low, then both nutrients should be applied (Fodder beet guide, 2008).

Boron (B) availability should be checked to prevent black heart disease (ADBFM, 2009), it is required for all root crops and beet is no exception. Typically broadcast 2-3 kg B/ha pre cultivation and where the soil test amount is less than 2 mg/kg. Figure (7) shows the clear symptoms of Boron deficiency in the soil.

Figure 7. Black heart disease symptoms, Hama Research Station, GCSAR, Syria.

Inputs will need to be appropriate for the target yield which may be 10, 20 or even up to 40t DM/ha. A typical 20 t DM/ha crop will remove (Fodder beet guide, 2008):

200 kg/ha Nitrogen.
60 kg/ha Phosphorus.
400 kg/ha Potassium.
30 kg/ha Sulphur.
40 kg/ha Calcium.
35 kg/ha Magnesium.

In News land (Fooder beet guide, 2008), it is recommended that once the crop is established and is close to canopy closure (when the leaves are almost touching between the rows), it is time to apply the last of the plant's nutrient requirements. This is generally a small application of Nitrogen, approximately 50–70 kg N/ha, depending on available soil N and rates prior to sowing.

Consider an additional application of Potassium if the plant requires it. This is also an ideal time to apply any trace elements, like Boron, if these were not applied at sowing or if the crop is seen to be deficient. A foliar tissue test may be required to confirm trace element deficiency.

When applying the fertilizer spray tracks as early as possible to avoid damage to bulbs. Once this is applied the crop should require no further inputs, including late insecticides as pests will generally leave larger fodder beet plants alone. From this time the beet plants will really start to achieve their yield potential. With a healthy canopy beet plants assimilate carbohydrates into bulb formation and it becomes evident why the inter row spacing is required.

In Syria the NPK application for fodder beet was as sugar beet (10, 120 and 120 Kg/ha respectively) (Al Jbawi *et al*., 2009; Al Jbawi *et al*., 2018). Figure (8) shows an experiment on the addition of different potassium levels on the productivity of fodder beet at Homs in Syria.

Figure 8. An experiment on the addition of different potassium level on the productivity of fodder beet at Homs Agricultural Research Center, GCSAR, Syria.

Seeding:

The suggested spacing between rows is 18–40 inches (Wrightson, 1889; Halligan, 1911; Eldredge *et al*., 2005; Al Jbawi, 2014). While narrower row spacing produces a higher yield per acre than wider spacing, it is important to select a row spacing that best accommodates your equipment, especially if you will be mechanically cultivating and harvesting the crop. Seed at a depth of 0.75–1.5 inches (Cattanach *et al*., 1991; Al JBawi *et al*., 2019), with an in-row spacing of 4–6 inches; thin seedlings to 6–10 inches apart (Halligan, 1911). The seeding rate should be 1–2 lbs per acre (Kurp *et al*., 2001).

Fodder beet seeds are protected by a thick coat. For more rapid and consistent germination, soak seed for 12 hours in warm water, spread seeds on a screen or cloth, and dry just enough to prevent them from sticking together (Wrightson, 1889). However, this method can have limitations with modern seeding equipment.

Seeds can be planted as early as February if weather is conducive, and as late as May if necessary, for summer harvest.

However, the main crop is normally sown in April. While earlier sowing dates generally result in heavier yields, there is also more risk due to unseasonably cold or wet weather (Wrightson, 1889). Sugar beets planted after mid-May in the Midwest have shown yield reductions of 1.5 tons for each week that planting is delayed (Cattanach *et al*., 1991).

In the south of England, fodder beets were sown in September or October and grown as a winter crop (Halligan, 1911). Sugar beet plants are tolerant to temperatures down to 25°F.

Irrigation:

Irrigation is required throughout the summer months for the crop to attain its maximum yield. A total of 8–12 inches may be needed depending on the variety. The total amount of water that should be applied need not vary with soil type, but irrigation frequency and rate should. For example, irrigate light sandy

soils more frequently but at a lower rate per application than heavier soils. Fodder beet crops are moderately tolerant to soil salinity and can withstand irrigation with saline water (Oyen, 2004). Fodder beet crops are moderately tolerant to soil salinity and can withstand irrigation with saline water (Oyen, 2004).

Cultivation:

Fodder beets are slow to germinate and if planted too early or in cold wet weather, weed seeds will germinate first and outcompete the seedlings (Halligan, 1911; Wrightson, 1889; Malden, 1891). Halligan (1911) suggested sowing a small amount of a quick-germinating crop such as buckwheat at either end of the fodder beet row as a marker. When the buckwheat emerges, which will occur up to several weeks prior to fodder beet emergence, cultivate between the rows to control weeds.

Early in the season, do not cultivate or throw soil into the fodder beet row, as this will bury and kill seedlings. Fodder beet growth habit is such that the growing point will extend above the soil surface over time, and by harvest one half or more of the root will be exposed (though this is based on variety). Once the crop growing point is an inch or so above the soil surface, it is effective to throw soil into the row for weed control. However, it is not necessary to
cover the root with soil.

Fodder Beet Pests and Diseases:

Fodder beet establishment can be compromised by occasional, localized, and seasonal pest and disease attack. Their impact can usually be minimized by management. Once established, fodder beet is typically disease free relative to other crops.

The most common Pests and Diseases Affecting Fodder Beet:

Fodder beet seedlings are susceptible at emergence to a range of pests. The main threats to an establishing crop in Syria were:

Greasy Cutworm (*Agrotis ipsilon aneituma*): it is a seedling insect pest, which attacks plants, especially seedlings ripped off at or just below ground level, young plants wilt. It can be controlled by chemicals, or crop rotation.

Powdery Mildew: which is a crop fungal disease, which appears like a white powdery substance on leaf surface. Evidence suggests a yield reduction may occur. It can be controlled by chemicals.

Brown Heart/Heart Rot: because of boron deficiency which creates the symptoms of the central leaves dying and rotting and can extend to the crown of the root which becomes hollow. To avoid this disease soil testing is important, and boron fertilizer application.

Yield:

Yields tend to increase in wetter climates or with irrigation by as much as 30% (Cattanach *et al*., 1991). Also, Fodder beet is particularly productive and is the highest yielding crop grown under temperate climates. Yields of 50-75 t of fresh roots/ha are common and up to 100 t fresh roots/ha can be obtained (Shalaby *et al*., 1989; Al Jbawi *et al*., 2009). The crop also produces 10-20 t/ha of leaf material (Draycott and Christenson, 2003).

The average fodder beet yield in England in the early 1900s was reported as between 20 and 40 tons per acre (Halligan, 1911). A variety trial in South Dakota in the early 1900s found an average yield of 16 tons per acre. A field trial from Pennsylvania found yields to range from 13 to 48 tons per acre (Ross *et al*., 2008). In Syria the root yield ranged from 30 to 60 tons per ha and sometimes it reached 100 tons per ha (Figure 9), while top yield ranged from 30 to 50 tons per ha (Al Jbawi *et al*., 2019).

Figure 9. High root and top yield of fodder beet at Hama Research Station, GCSAR, Syria

Harvest:

Fodder beet roots can be harvested when physiological maturity is reached, *i.e.* when basal leaves are dried. However, as roots do not spoil in soil, early harvest is not necessary and roots can remain in the soil as long as no damaging frost occurs. If the roots are removed from the soil, they can be stored in large outdoor clamps provided temperatures do not drop below - 5°C. They should then be covered with straw. It is possible to store fodder beet roots for 4 to 5 months provided they are healthy and were undamaged during harvest. Frozen beets can be left to thaw and must then be fed to animals as soon as possible. Severely diseased beets should be avoided, and those mildly diseased should be kept separately to healthy ones and fed as soon as possible (ADBFM, 2009). Fodder beets that have been frozen in the field will quickly rot in storage.

Top the crop (remove leaves) to within 2–4 inches of the top of the root or allow animals to forage the tops off, but ensure that the animals do not uproot the beets. Complete leaf removal is important to prevent re-sprouting if you are storing in piles (Cattanach *et al.*, 1991). It is not necessary to remove all the soil from the roots, as some soil can improve root storability, but it does need to be removed prior to feeding. Fodder beets that are cut or damaged by harvesting equipment will likely rot in storage. Similarly, if tops are cut too close to the root, the root will be more susceptible to rot (Wrightson, 1889). Sugar beet lifter-loader harvesters pull beets from the soil, remove much of the soil from the root, and load roots onto trucks. Large-scale modern sugar beet harvesters are expensive, so you may want to consider older used equipment which is often available in traditional sugar beet production areas. Fodder beet roots that have been previously cleaned (stones and soil removed using rotating drums) can be fed whole to animals or can be chopped to facilitate intake (ADBFM, 2009; Miserque and Oestges, 2003).

In cooler parts of the tropics the roots can be stored in the ground for use during the dry season (Göhl, 1982).

It is worth to mention that Root crops cause soil losses during harvest (Ruysschaert *et al*., 2004). Sugar beet harvesting may result in 17 t earth losses/ha. Fodder beet roots are less heavily grooved

than sugar beet roots and, therefore, lift less soil when they are harvested (Boardman and Poesen, 2006).

Pasture:

Fodder beet roots and foliage can be grazed. Strip grazing is recommended: cattle enter the stand and each animal is allowed to graze 3 linear meters of fodder beet for 2 hours a day. Grazing saves many harvesting and distribution operations (ADBFM, 2009). Strip grazing with pigs is also possible (Limagrain, 2011).

In New Zealand in the past decade, a new system of fodder beet feeding has been developed, where cattle and sheep graze the crop in-situ as a primary diet, with minimal additional roughage used. This method has proven very productive in dairy, beef and sheep systems, and on the back of this, fodder beet has become the fastest growing hectarage in New Zealand history, with approximately 500 000 stock grazing beets in 2016.

The leaf is not toxic, and can be safely grazed from early autumn forward, contrary to earlier European ideas. The leaf is important to grazing stock as it carries much of the protein of the plant, and matching this with the energy of the bulb is a central management tool in beet grazing.

Beet systems for use in dairy cows are split between dry cow and lactation feeding. Dry cow systems use high intake grazing, while lactation feeding uses beet at a lower input rate to replace expensive cereal and silage supplements. Both are significantly less expensive than alternative feeds, and reduce the cost of production.

Beef systems use beet as a finishing diet to accelerate the cattle to earlier slaughter ages. The system is not only far more cost effective than other feeding strategies, such as grain feeding, but also has a number of key advantages in both the carcass produced, and the environmental footprint of production. Annual carcass production of above 2500 kg/hectare has been demonstrated in these systems, with growth rates in yearling cattle above 1 kg daily published. It is proving a pivotal contribution to the ability of pasture fed beef production systems to supply high quality carcasses all year around.

Sheep systems uses beet grazing for wintering pregnant ewes and replacement stock, and also for autumn and spring shoulder feeding to effectively increase stocking rates and conserve pasture for use after lambing. Prime lamb systems use autumn to winter grazing as a means of holding high volumes of stock on small areas, enabling early season purchasing of lambs at significantly reduced prices.

Storage:

Because fodder beet palatability increases with age, roots should be stored for a few months before being used. They will reach optimal palatability the summer after harvest. Historic records show they can be stored for a second winter and still maintain nutrient content and palatability (Wrightson, 1889).

In areas where soil does not become saturated over the winter, dig a shallow pit and fill with harvested fodder beets; cover with 4–6 inches of soil and an additional 6 inches of straw to protect from freeze damage (Wrightson, 1889). Another recommended storage option is to stack roots in a long pile, 6–14 feet wide at the base and 4–10 feet high at the apex, on level or unpaved ground either

against a building or in the open. Ventilation systems may be incorporated into piles to reduce sugar loss through root respiration and rot (Cattanach *et al*., 1991). Dig an 8-inch deep trench around the pile for drainage; place the soil over the fodder beets. Cover with straw to a final thickness of at least 10 inches.

Fodder Beet and 'Bolters':

Some growers are ignoring best practice and opting for 'beet on beet' instead of a crop rotation. This practice requires even more active monitoring of bolting beets with immediate removal of these plants from the paddocks, ensuring that fodder beet can be grown
sustainably in the future.

Beet following beet has the additional issue of bolters, generated by leftover bulbs or bulb chips from the previous crop. If all or part of these bulbs remain in the ground with a viable root system, these plants (being over 12 months old) will naturally go to seed through their second summer. Each individual bolter can produce up to 6,000 seeds which can stay in the soil for up to 10 years.

Also, having a crop rotation with beet following beet is very risky and increases the chances of weed beet build up as well as the introduction of crop limiting diseases and pests.

Environmental benefits of Fodder beet:

- Fodder beet crops are amongst the largest consumers of CO_2; they also release the highest amounts of O_2 (Kerten, 2003).
- It is also a potential crop for biofuel production (Henry, 2010).

Genetically modified fodder beet:

Genetically modified fodder beet (Roundup Ready) has been developed but in 2011 no such variety had been released in Europe (GMO Register, 2011). Field trials were authorized in Denmark in 2005 for a four-year period. Digestibility and feeding values of Roundup Ready fodder beet were similar to those of conventional varieties (Hartnell et al., 2005). The GM fodder beet resulted in milk yields intermediary to those of 2 different types of conventional fodder beet. Fodder beet type did not affect the concentration of hormones and growth factors in whey (Weisbjerg *et al*., 2001).

Fodder Beet Grower Checklist:

- Select free draining fields that are able to be prepared to a good standard.
- Avoid fields where previous crops have had residual chemicals applied.
- Soil test early using a 100mm soil probe. Test pH of fields being considered for fodder beet well before sowing. A pH (water) above 6 is required, ideally 6.2.
- Spray out and prepare seed bed as early as possible using a double spray program if necessary.
- A fallow period should be used to help conserve soil moisture.
- Fertilizer use should be based on a recent soil test, fertilizer should not be applied with the seed.
- A fine, firm seed bed is essential.
- Apply insecticides prior to or at drilling if required, monitor for insect pests post establishment.
- Sow into adequate soil moisture from when soil temperature is at least 10˚C (pay attention to evening time soil temperatures as well as day time and check last frost date).
- Best results are achieved using a precision drill. Sow seeds at 1.5–2.0cm depth. Make sure coulters are set to an even depth.
- Sow one full box per hectare (80-100,000 seeds/ha), when using a precision drill.
- Drill speed should be low to avoid poor seed placement, 4-5 km/hour maximum.
- Apply post plant/pre emergence herbicide after sowing. If conditions are dry this may have to be applied and incorporated prior to sowing.

- Plan your herbicide program based on expected weeds and to avoid delay in correct timing of application.
- Apply when the crop has at least two true leaves and before weeds reach the four true leaf stage.
- Apply second nitrogen and potassium application after weed control for maximum yield.

References:

Abdallah, E.F.; and A.A. Yassen (2008). Fodder beet productivity under fertilization treatments and water augmentation. Australian Journal of Basic and Applied Sciences. 2(2): 282-287.

Abel, S.; C.A. Ticconi; and C.A. Delatorre (2002). Phosphate sensing in higher plants. Physiologia Plantarum. 115:1-8.

ADBFM, (2009). La betterave fourragère de A à Z. Association pour le Développement de la Betterave Fourragère Monogerme, Paris. http://www.betterave-fourragere.org/doc/Betterave%20Fourragere%20AZ%20V7.pdf.

Al-Jbawi, E.M.; S. Al-Jeddawy; M. Yabrak; and S. Khuja (2009). Sugar Beet. Publications of the Directorate of Agricultural Extension, Ministry of Agriculture and Agrarian Reform, Syrian Arab Republic. No, (482), 33 pages. (In Arabic). http://gcsar.gov.sy/elibrary/%D8%A7%D9%84%D9%86%D8%B4%D8%B1%D8%A7%D8%AA-%D8%A7%D9%84%D8%A5%D8%B1%D8%B4%D8%A7%D8%AF%D9%8A%D8%A9/

Al-Jbawi, E.M. (2012). Fodder beet. Journal of Agriculture, Ministry of Agriculture publications, no. 41. (In Arabic) http://moaar.gov.sy/site_ar/agrimag/mag41/41.pdf

AL-Jbawi, E.M.; M. Bagdadi; and Y. Nemr (2014). The effect of plant spacing on some quality traits of fodder beet (*Beta Vulgaris* var.*crassa*) varieties. International Journal of Environment. 3(3): 286-293. http://www.nepjol.info/index.php/IJE/article/view/11089

AL-Jbawi, E.M.; M. Bagdadi; and Y. Nemr (2015). The productivity of four fodder beet cultivars (*Beta vulgaris* var. *crassa*) affected by autumn and winter sowing. International Journal of Environment. 4(3): 121-129. http://www.nepjol.info/index.php/IJE/article/view/13235/10677

Al-Jbawi, E.; S. Shamsham; and H.Sh. Aldeen (2018). The response of some productivity and quality traits of fodder beet (*Beta vulgaris* L.) to organic and potassium fertilizers in Syria. Journal of Sugar Beet. 34(1):0-0 short paper. DOI: 10.22092/JSB.2018.121594.1190, http://jsb.sbsi.ir/article_117126_en.html

Al-Jbawi, E.M.; A. Mohanna; and J. Mansour (2019). The response of some productivity and quality traits of five fodder beet cultivars (*Beta vulgaris* L. var *Crassa*) to sowing dates. Agrica. 8(1): 23-31. DOI : 10.5958/2394-448X.2019.00003.8. http://www.indianjournals.com/ijor.aspx?target=ijor:agr1&volume=8&issue=1&article=004.

Anonymous (2006).http:// www. Seed 2 grow. Co. UK/acatalogy/Fodder-Beet- seed. himl (2006).

Barnes, R.F.; D.A Miller; and C.J. Nelson (eds) (1995). Forages, Volume I: An Introduction to Grassland Agriculture. 5th ed. Ames, IA: Iowa State University Press.

Bath, D.L. (1980). By-products and unusual feedstuffs in livestock rations. Western Regional Extension Publication. No. 39.

Boardman, J.; and J. Poesen (2006). Soil erosion in Europe: major processes, causes and consequences. in Soil Erosion in Europe (eds J. Boardman and J. Poesen), John Wiley and Sons, Ltd, Chichester, UK. http://dx.doi.org/10.1002/0470859202.ch36

Bull, S. (1916). the principles of feeding farm animals. New York: Macmillan, http://chla.library.cornell.edu/cgi/t/text/textidx?c=chla;idno=272705.

Blumenthal, J.M.; B.D. David; C.G. Kenneth; M.C. Stephen; and P.A.D. Alexander (2008). Importance and effect of nitrogen on crop quality and health. In: Nitrogen in the Environment: Source Problems and Management. 2nd edition. Elsevier Inc. Amsterdam, pp. 51.

Card, L.E.; and M. Henderson (1933). Farm poultry production. Danville, IL: The Interstate Printing Co., http://chla.library.cornell.edu/cgi/t/text/textidx?c=chla;idno=280250.

Cattanach, A.W.; A.G. Dexter; and E.S. Oplinger (1991). Sugar beets. Alternative Field Crops Manual, http://www.hort. purdue.edu/newcrop/afcm/sugarbeet.html. Cornell University. 2006. Rutabagas. Cornell Vegetable.GrowingGuides,http://www.gardening.cornell.edu/homegardening/scened5c9.html.

Delwiche, E.J. (1924). Root crops are profitable. The University of Wisconsin Agricultural Experiment Station, Bulletin 330.

Draycott, A.P.; and D.R. Christenson (2003). Nutrient for sugar beet production, soil-plant relationships. ©CAB International 2003. ISBN 0 85199 632 X. Pp241. http://books.google.fr/books?id=acQ-QEanvCgC

Ensminger, M.E.; and C.G. Olentine (1980). Feed and nutrition complete. Clovis, CA: Ensminger Publishing Co.

Eldredge, E.P.; C.C. Shock; and L.D. Saunders (2005). Sugar beet variety 2004 testing results. OSU Agricultural Experiment Station, Special Report 1062: p. 186-193.

El Sarage, E. (2013). Response of fodder beet cultivars to water stress and nitrogen fertilization in semi-arid regions. American Eurasian J. Agric. and Environ. Sci., 3 (9): 1168-1175.

Frese, L.; B. Desprez; and D. Ziegler (2001). Potential of genetic resources and breeding strategies for base-broadcasting in *Beta*. In, Braodcasting the genetic base of crop production (eds H.D. Cooper; C. Spillane and T. Hodgkin). ©IPGRI/FAO 2001. Chapter 17: 295-309.

Fodder beet guide (2018). AGRICOM.CO.NZ.

GMO Register, (2011). Genetically modified Round Up ready fodder beet (A5/15) in Danish field trials - Deliberate releases and placing on the EU market of genetically modified organisms. European Commission, Joint Research Centre, Institute for Health and Consumer Protection, Notification Report B/DK/05/01. http://gmoinfo.jrc.ec.europa.eu/gmp_report.aspx?CurNot=B/DK/05/01

Göhl, B., (1982). Les aliments du bétail sous les tropiques. FAO, Division de Production et Santé Animale, Roma, Italy. http://www.fastonline.org/CD3WD_40/JF/414/05-222.pdf

Gower, S.; R. Butler; and S.D. Armstrong (2006). Yield comparisons of old and new cultivars of Swedes (*Brassica napus* ssp. *napobrassica*) in Southland, New Zealand. New Zealand Journal of Crop and Horticultural Science. 34: 109-114.

Gullickson, T. (1943). Feeding dairy cattle. Saint Paul: Webb Book Publishing Company, http://chla.library. cornell.edu/cgi/t/text/text-idx?c=chla;idno=2802598.

Halligan, J. (1911). Fundamentals of Agriculture. New York: D.C. Heath & Company. http://chla.library.cornell. edu/cgi/t/text/text-idx?c=chla;idno=2741178.

Hartnell, G.F.; T. Hvelplund; and M.R. Weisbjerg (2005). Nutrient digestibility in sheep fed diets containing Roundup Ready or conventional fodder beet, sugar beet, and beet pulp. J. Anim. Sci., 83 (2): 400-407. http://www.journalofanimalscience.org/content/83/2/400

Henry, K. (2010). Fodder beet. In: Tuber and root crops, Handbook of plant breeding 7 (ed. J.E. Bradshaw), 221-243. New York: Springer Verlag. http://books.google.fr/books?id=kHE2nlLLCAAC

Heuze, V.; G. Tran; and D. Sauvant (2015). *Fodder beet roots*. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. https://www.feedipedia.org/node/534.

Højland, J.G.; and S. Pedersen (1994). Sugar beet, beetroot and fodder Beet (*Beta vulgaris* L. subsp. *vulgaris*): Dispersal, establishment and interactions with the environment. The National Forest and Nature Agency, Copenhagen, Denmark. 73 p.

Hopp, W.J.; and M.P. Oyen (2004). Agile workforce evaluation: a framework for cross-training and coordination. Lie Transactions. 36(10): 919-940.

HTTP://www.biologie.uni-hamburg.de/b-online/schaugaren/varalba/fodder-beet 2006.

Ibrahim, Y.M. (2005). Ranges and forage (In Arabic). Dar Azza for Publication, Khartoum, Sudan. Pp 300.

Kanchikerimath, M.; and D. Singh (2001). Soil organic matter and biological properties after 26 years of maize-wheat-cowpea cropping as affected by manure and fertilization in a Camisole in semiarid region of India. Agric. Ecosyst. Environ., 86: 155- 162.

Kerten, J.L. (2003). La betterave fourragère, une culture oubliée?. In: La betterave fourragère chez vous? Après-midi d'étude du 3 décembre 2003 consacrée à la betterave fourragère organisée par le Centre Agricole « Fourrages Mieux » à la ferme Expérimentale et Pédagogique de Ath, Belgique. http://www.fourragesmieux.be/betterave.htm

Kurp, E.L.; C.H. Daniels; D. Bowers; J. Bair; and E. Bair (2001). Crop profile for sugar beets in Washington. Washington State University, http://www.ipmcenters.org/CropProfiles/docs/WAsugarbeets.html.

Limagrain, (2011). Fodder beet. Limagrain UK. http://www.limagrain.co.uk/products/fodder-beet.html

Marschner, H. (1995). Mineral nutrition of higher plants. Academic press San Diego, USA.

Matthew, C.; N.J. Nelson; D. Ferguson; and Y. Xie (2011). Fodder beet revisited. Proceedings of the Agronomy Society of New Zealand. 41: 39-48.

Malden, W.J. (1891). Tillage. London: George Bell and Sons, http://chla.library.cornell.edu/cgi/t/text/textidx?c=chla;idno=271629.

Miserque, O.; and O. Oestges (2003). La distribution des betteraves fourragères. In: La betterave fourragère chez vous? Après-midi d'étude du 3 décembre 2003 consacrée à la betterave fourragère organisée par le Centre Agricole « Fourrages Mieux » à la ferme Expérimentale et Pédagogique de Ath, Belgique. http://www.fourragesmieux.be/betterave.htm

Niazi, B.H.; J. Rozema; R.A. Broekman; and M. Salim (2000). Dynamics of growth and water relations of fodder beet and sea beet in response to salinity. Journal of Agron and Crop Sci., 184: 101-109.

OECD, (2001). Consensus document on the biology of *Beta vulgaris* L. (sugar beet). Environment Directorate. Series on Harmonization of Regulatory Oversight in Biotechnology No. 18. Joint meeting of the chemicals committee and the working party on chemicals, pesticides and

biotechnology. http://www.oecd.org/officialdocuments/displaydocumentpdf/?cote=env/jm/mono%282001%2911&doclanguage=en

Ohio, Vegetable Production Guide, (2009). Radishes, turnips, and rutabagas (Swede Turnips). Ohio State University, http://ohioline.osu.edu/b672/pdf/Radishes.pdf.

Oregon State University (OSU), (2004). Rutabaga (Swede) and Turnip. Commercial Vegetable Production Guides, http://hort-devel-nwrec.hort.oregonstate.edu/rutabaga.html.

Oyen, L.P.A. (2004). *Beta vulgaris* L. Record from Protabase. Grubben, G.J.H. and Denton, O.A. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. http://www.prota4u.org/

Reddya, A.R.; K.V. Chaitanya; and M. Vivekanandanb (2004). Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. J. Plant Physiol., 161: 1189-1202.

Rees, D.H.; and M.H. Westmacott (1956). The feeding of fodder beet to pigs. J. Agric. Sci., 47: 232-237. http://dx.doi.org/10.1017/S0021859600040168

Ross, G.G.; D. Buffington; C. Houser; and M. Antle (2008). Evaluation of fodder beets as a feedstock for PA ethanol production. Crop Management Research Report 02-2008, http://downloads.cas.psu.edu/RenewableEnergy/Fodder-beetReport08.pdf.

Ruysschaert, G.; J. Poesen; G. Verstraeten; G. Govers (2004). Soil loss due to crop harvesting: significance and determining factors. Progress in Physical Geography, 28 (4): 467-501. http://dx.doi.org/10.1191/0309133304pp421oa

Schoth, H.A. (1957). Root crop production for livestock. U.S. Department of Agriculture, Leaflet No. 410.

Shalaby, A.S.; A.M. Rammah; G.M. Abdul-Aziz; and M.G. Beshay (1989). Fodder beet, a new forage in Egypt. 1. Productivity and the chemical analysis of some Fodder beet (*Beta vulgaris* L.) cultivars sown at different locations in Egypt. In proceedings of the third Egyptian British Conference on Animals, fish and poultry production. Alexandria, Egypt, 13: 133-143. [C.F. Nadaf, S.K., Ibrhaim, Y.M., Akhtar, M., El Hag, M.G. and Al-Lawati, A.H., (1998a). Performance of Fodder beet in Oman. Annals of Arid Zone. 37 (4): 377-382.

Shepard, J.H. (1918). Sugar beets and other roots as stock feed. In Root Crop Culture in South Dakota. South Dakota State College of Agriculture and Mechanical Arts, Brookings. Bulletin No. 180, pp. 850-853, http://pubstor-age.sdstate.edu/AgBio_Publications/articles/B180.pdf.

Smith, H.R. (1905). Profitable stock feeding: A Book for the Farmer. St Paul, MN: University Farm, http://chla.library.cornell.edu/cgi/t/text/text-idx?c=chla;idno=2709049.

Šrek, P.; M. Hejcman; and E. Kunzová (2010). Multivariate analysis of relationship between potato (Solanum tuberosum L.) yield, amount of applied elements, their concentrations in tubers and uptake in a long-term fertilizer experiment Original Research Article. Field Crops Research. 118(2): 183-193.

Vance, C.P. (2008). Plants without arbuscular mycorrhizae. Plant Ecophysiology. 7:117-142.

Watson, L.; and M.J. Dallwitz (1992). The grass genera of the world. 1038 pp. CAB International, Wallingford.

Weisbjerg, M.R.; S. Purup; M. Vestergaard; T. Hvelplund; K. Sejrsen (2001). Studies on genetically modified fodder beets for dairy cows. DJF Rapport, Husdyrbrug. 25: 39 pp.

Wickson, E.J. (1897). The california vegetables in garden and field: A manual of practice, with and without irrigation, for semitropical countries. San Francisco: Pacific Rural Press, http://chla.library.cornell.edu/cgi/t/text/textidx?c=chla;idno=2717761

Wilson, J. (1859). Our farm crops. Vol. I. London: Blackie and Son. Wrightson, John. 1889. Fallow and Fodder Crops. London:

Chakwizira, E.; A.L. Fletcher; E. Meenken; P. Johnstone; S. Maley; N. Arnold; S. Armstrong; M. George; R.E. Sim; R. Minchin; J.D. Morton; and A.D. Stafford (2011). Dry matter response of swede crops to phosphorus (P) and nitrogen (N) application in Southland and central North Island regions of New Zealand. Proceedings of the Agronomy Society of New Zealand. 41: 23-37.

Chapman and Hall, http://chla.library.cornell.edu/cgi/t/text/text-idx?c=chla;idno=2920861.

Wrightson, J. (1889). Fallow and fodder crops. Cornell University Library 2009. ISBN-13: 978-1112242649. Pp 379.

Wilson, D.R.; J.B. Reid; R.F. Zyskowski; S. Maley; A.J. Pearson; S.D. Armstrong; W.D. Catto; and A.D. Stafford (2006). Forecasting fertilizer requirements of forage brassica crops. Proceedings of the New Zealand Grassland Association. 68: 205-210.