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Influence of Main Stem Density on Irish Potato Growth and Yield: A Review

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AS and RM wrote the first draft. Author TM managed literature searches. Author UM designed the layout, guided the process and wrote all subsequent versions of the review. All authors read and approved the final manuscript.

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ABSTRACT

Our review confirms that stem density is affected by seed factors, seedbed conditions and planting methods. Physiologically old seed tubers develop into a 'weak' stem density. A loose friable soil that is warm and moist increases sprout emergence leading to a high stem number per hill. This high stem density can be achieved through the use of large seed tubers at planting. The greater the stem densities the higher the yield since more tubers are obtained per plant. An increase in inter stem competition associated with high stem desnity results in a decrease in harvestable tuber weight and size. However, our findings were inconclusive on the influence of varietal differences and planting depth on stem density. The influence of stem density on tuber specific gravity is also yet to be fully understood. We reiterate that producers for ware consumption should aim for low stem populations per hill while conventional seed producer are encouraged to take advantage of higher stem densities.

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1. INTRODUCTION

Potato stems can be either a main stem, which grows directly from a seed tuber, or a secondary stem if it branches off the stem. Secondary stems may also arise at the point where stolons intersect the ground surface to produce leaves. The potato stem system forms part of the stolons and tubers. Plants grown from tubers have more main stems than those derived from true seed. The general crop performance, harvestable yield and tuber size are strongly influenced by stem numbers per hectare. Therefore, there is need to plant seed tubers that have a high number of strong sprouts. It is widely accepted among researcher [1–4] that regardless of the higher yields derived from high stem populations, average tuber size is compromised. Thus, there is need to determine an optimum level of main stems per plant. However, this is largely influenced by the purpose of the intended potato crop. There is a plethora of factors affecting stem density and their subsequent effect on the performance of the potato plant is outlined below. We covered papers from 52 workers in this review.

2. WHAT IS STEM DENSITY?

A potato plant usually is made up of more than one stem. Each individual stem gives rise to both below and aboveground biomass. This means that a single stem produces its own roots, stolons, tubers, foliage and inflorescences thus behaving as a single production unit. A number of definitions have been put across to define stem density. The stem density of a potato crop is the number of stems per unit area and differs significantly from the plant population mostly given in recommendations. The density of the potato crop consists of two components. The first component is the number of plants generally referred to as plant density and the second, is the number of stems per plant. Plant density refers to the number of tubers planted per unit area while stem density refers to the number of stems arising from each tuber mainly because each tuber has a number of “eyes”, each of which can produce a stem.

3. SIGNIFICANCE OF STEM DENSITY ON POTATO PRODUCTION

Research on potato stem density has improved our understanding of the morphology and physiology of the potato plant. Each stem from a single eye can be regarded as an independent production unit. Thus, a sufficient number of strong stems should develop per seed tuber. Investigations on stem density levels have also provided an insight on yield and quality of harvested tubers. A comprehensive understanding of this concept can be used to manipulate the production of ware and seed potatoes.

4. FACTORS INFLUENCING MAIN STEM DENSITY

A number of factors affect main stem density per planting station. According to [4], main stem numbers depend on seed bed conditions, planting method and seed tuber characteristics such as number of eyes or sprouts, size, physiological age and variety. Seed factors are by far the most influential as they govern the number of main stems that can emanate from a seed tuber. The age of the seed tuber is an important determinant of stem density also [5]. The age of the seed tuber determines the degree of sprouting. Reference [6], classified the age of potato seed into chronological and physiological age. Chronological age is a measure of days after harvest while internal biochemical processes determine physiological age. The physiological aged of seed tubers is most significant with regard to stem density. Reference [7] classified seed age into dormant, young, middle and old. There are a number of factors influencing the rate of physiological aging: growing season stresses, storage temperature and time, and others [8]. Young seed has a few sprouts that emerge slowly and hence produce a few main stems [5,9]. The presence of internal inhibition limits sprouting at both the distal and dorsal ends of young seed tubers [7]. Multiple sprouts that have a hairy appearance characterize physiologically old seed tubers. The sprouts are generally weak but emerge rapidly giving rise to more stems per hill [10]. However, under field conditions, physiologically old seed tubers give poor stands and exhibit delayed foliage development, resulting in early tuber initiation. There is also a general agreement among researchers that old seed tubers result in high tuber setting but yields smaller tubers [11,12] .

5. THE SEED BED CONDITIONS

Soil conditions are influential in determining the extent of sprout survival and emergence. Soil conditions as influenced by the soil structure, moisture and temperature affect emergence of sprouts. A soil with platy or blocky aggregates will impede emergence of fragile sprouts. Thus stem density is low under a compacted seedbed [4]. A loose friable soil ensures free emergence with limited resistance to sprouts and ensures adequate oxygen and moisture retention for the growth tissues [13]. It is essential for the seed tuber to have adequate contact with soil moisture. Sufficient moisture ensures reduced impediments to the emergence of sprouts and supports rapid root development. This has the potential of increasing the vigor of the sprout. Excessive soil moisture may, however, reduce soil oxygen levels and suffocate the emerging sprouts. Soil temperature also affects the spread of sprout growth and emergence. Warm soils are most likely to increase emergence, thereby increasing stem numbers while cool soils (below 15ºC) retard emergence and eventually stem density [13]. Work by reference [14] showed that temperature had a considerable effect on stem populations. Stem numbers increased when seed tubers were planted in warmer soils [10].

6. PLANTING DEPTH

The depth of planting also influences the number of emerging stems per tuber. Generally, the planting method determines the depth at which the seed tuber is planted. A suitable planting method ensures survival and emergence of all sprouts developing from a seed tuber. The effects of planting depth on stem density have been directly or indirectly investigated by a number of researchers [5,9,15–17] who reported contrasting results.

Delayed crop emergence and possibly a reduction in stem numbers as planting depth increased was reported by references [5] and [18]. Work by reference [9] showed an acceleration in emergence rate at shallow plantings. The work also showed a varietal related response of stem density to planting depth. Below and above ground morphological responses to planting depth have been observed. Tuber number, stolon and node per stem increased with an increase in planting depth [9]. The effect of warm soil temperature, which resulted in the accumulation of more growing degree-days at shallow plantings, may account for the increase in stem density observed in Russet Burbank. Work by reference [10] showed an increase in stem density when tubers were planted in warm soils. High stem densities have also been observed from deeper planted seed tubers, suggesting that temperature and moisture were important factors [15,18,19].

7. SEED SIZE

The size of the seed tuber is a major determinant of stem density and generally the larger the seed potato, the more stems produced [24]. The size of the seed tuber is directly related to the number of stems [2,20]. Reports from reference [21] showed seed size to have minimal effect on stem number as most stems originated from only one eye at the apical section of the seed tuber. Reference [22] asserted that despite the slight increase in stem numbers with an increase in seed size, many other factors influence stem numbers per seed unit. However, more stems are obtained per unit seed weight when the average weight of seed is smaller. This is because the smaller the seed-potatoes, the more the stems, which can be obtained from an average quantity of seed-potatoes since their combined eyes could be larger.

8. VARIETIES

Varietal differences exist with regard to stem density. Seed tubers of different genetic composition are known to differ in stem numbers [23,24]. However, more work is needed to evaluate the contribution of variety to stem production. Some cultivars have numerous eyes and sprout much more profusely than others. However, there is still need to characterize potato varieties with respect to stem density per seed unit. Genetically, some cultivars might produce tubers with a higher number of eyes and consequently sprout more than others. Reference [25] reported that certain cultivars, regardless of their ability to yield large sized tubers produce a higher percentage of blind tubers. A greater proportion of blindness or fewer developed eyes per seed tuber resulted in a reduction in stem density. No studies have been done on the influence of cultivars such as Jasper, Montclair, Pimpernel, Amethyst, KY20 and 89 on stem density and canopy development.

9. INFLUENCE OF MAIN STEM DENSITY ON CANOPY GROWTH

Stem density is most likely to influence emergence of the potato crop and conversely, conditions that govern sprout emergence influence stem numbers. There is however, no clear-cut position on how plants established at diverse densities have performed during the seedling emergence period. From the studies carried out by reference [26], the number of eyes and stems produced per seed piece increased as cut seed piece size increased, presumably because as the seed piece increased the chances of carrying more eyes also increases. It is widely accepted that the average number of sprouts per seed tuber indicates the expected number of stems. Studies by reference [13] suggested that tubers with multiple sprouts can have a significant competitive edge over tubers with a fewer eyes or less sprouts as they can produce several strong seedling per unit area.

The potato plant has a compound leaf, each with 3-4 leaflets that are ovate in shape. The top leaflet found at the rachis end is often the largest and has a shape that is slightly different from the other large leaflets. The small leaflets are ovate to sub orbicular in shape [27]. Leaflets are attached spirally to the stem. A stalk joins the leaflets onto the midrib. The angle of insertion of the petiole on the stem and size and form of the two small lateral (pseudo-stipular) leaves are often useful in distinguishing varietal characteristics [28]. Leaves form the significant part of plant's photosynthetic apparatus.

There is relatively limited information available on the effects of stem density on leaf appearance, leaf senescence and lateral brunching [29].There is room for extensive study in the characterization of leaf and stem morphology as a response to stem density [21]. However, substantial evidence support the notion that stem density has considerable impact on the leaf production of a plant's canopy.

The initial growth phases are most likely to be characterized by a high leaf area production by high stem density established plants. The rise in leaf area appears to be influenced by the high number of main stems that emerge. The phenomenon was reported by reference [30] who observed an increase in leaf area during the initial growth phase at high density. A reduction in inter-stem competition at low densities is most likely to favor the production of a robust canopy when the stems are fewer. Reference [31] also reported that low stem densities had access to sufficient nutrients and sunlight. This resulted in an increase in photosynthetic efficiency giving rise to luxurious rank growth. Findings by reference [32], showed that leaf area increased with a decrease in stem density.

An increase in lateral branching at low stem densities as reported by references [33,29,33] is a major contributor to leaf area. At low stem densities, production of basal lateral branches is more vigorous as the crop attempts to increase its ability to intercept photosynthetic active radiation (PAR). Sufficient nutrient resources are also available for development of a large source in preparation for the tuber initiation and development processes. Increased inter -stem competition among high stem densities reduced the allocation of accumulated assimilates to production of the photosynthetic apparatus [34]. The result was poor vegetative growth [31]. Finding by reference [29] indicated that basal and lateral branching decreased at high stem densities as a consequence of increased inter-stem competition. Some workers [31,33,35] also observed a decrease in branching at high stem population.

Stem populations largely affect crop access to resources including solar radiation and nutrients. Adjustment of stem density is considered one of the most important and effective way of improving potato yield [36].The number of eyes may determine stem number per seed piece and similarly, it was found that stem density was positively correlated with eye number per seed piece in cultivars such as Nooksack [25]. Growth is limited when competition among stems is high. Generally, it is widely accepted that as stem populations per station increases, the height of the growing plants is reduced. Competition for essential nutrients among plants increases with an increase in stem population. In essence, stem height increases with a decrease in inter-stem competition for growth elements. Reports by reference 29 and 34 showed an increase in stem length at low stem density and attributed this to low competition for both nutrients and photosynthetic active radiation. However, research on manipulation of stem populations at various intra row spacing have suggested that stem height increases with an increase in plant density, arguably, as stems compete for light. Studies by reference [3,35] showed that tallest plants were obtained at higher plant densities.

10. YIELDS

Stem density has the greatest influence on dry matter accumulation. With regard to stem density, the number of tubers produced depends on the competition for growth factors among the stems. Since each single main stem is regarded as a production unit, the yield of harvested tubers is most likely to vary with increase in stem numbers. Reference [37] observed that more tubers were produced at high stem densities. Reference [38] also noted an increase in tuber number to a maximum of 190 tubers/m^2 as stem populations increased. Reference [39] and [40] also recorded a marked increase in tuber numbers as stem densities increased per unit area.

However, it is possible to get high tuber counts at low stem densities. Minimum competition for nutrient factors, space and exposure to adequate radiation interception adds to the potential for increasing tuber counts [31].

Nevertheless, as much as higher stem densities result in greater yield they also affect the size of tubers. Growth is affected when competition among stems is high. At higher stem densities, the tubers produced are smaller than at lower stem densities. Regardless of the increase in tuber number, average tuber size is reduced, which affects the total marketable tubers [41]. Tuber weight decreased as stem density was increased [42]. At higher stem densities, the tubers produced were smaller than at lower stem densities, while the percentage of large tubers decreased [2]. The tuber yield of potato varieties severely diminished as stem density increased [43].

Controlled environment studies conducted to characterize differences in canopy growth and dry matter production among single and multiple stemmed potatoes showed that vegetative and yield dry matter production were unaffected by stem density. As stem density increased, fewer tubers were produced and this was due to reduced multiplication rate which was defined as number of tubers produced per seed tuber [29].

11. QUALITY

Stem density is most likely to affect the quality of the harvested tubers in a way that might increase or decrease the economic value of the entire harvest attained. At higher stem densities, the tubers produced were smaller than at lower stem densities while the percentage of large tubers decreased [2]. Total harvestable and marketable yields expressed diminishing returns as stem density increased [44]. Therefore, the proportion of non-marketable yield is most likely to increase with increasing stem density. This is because of an increase in the competition for water, nutrients and sun light among high density crops during tuber bulking and confirms work by reference [45] and [41]. They reported a reduction in total marketability of tubers as stem populations increased.

The specific gravity of potatoes is an important quality determinant for processing potatoes. Specific gravity is an important estimate of solids and dry matter content of tubers [46] and the higher the specific gravity or dry matter the lower the water content of tubers. Processors in the French fry industry require potatoes with a high specific gravity or dry matter as such potatoes absorb less oil during frying. At high stem populations, increased inter-stem competition for nutrients and other growth factors lowered the specific gravity of tubers, while at low stem densities, optimum utilization of nutrients per stem decreased tuber specific gravity [31]. However, findings by reference [35], also showed that the specific gravity of tubers decreased at low stem densities. According to reference [46], a very positive correlation existed between specific gravity and tuber dry matter. Thus, dry matter content may respond with the same trend as specific gravity at the extremes of stem density. Reference [47] reported a decrease in tuber dry matter at high stem density. Findings by reference [48] reported high dry matter accumulation of tubers at low stem densities. This validated the general consensus among researchers [31,46–49] that competition extremes (low and high) negatively impact specific gravity and tuber dry matter.

The potato plant when exposed to direct sunlight develops a green pigment, which is caused by chlorophyll formation, and this renders the affected tuber unfit for marketing. Chlorophyll formation in the tuber results in the accumulation of Glycoalkaloids. Glycoalkaloids can result in potatoes developing a bitter taste and if consumed in high concentrations can be toxic to humans [50]. There is a greater possibility of obtaining a high number of green tubers at high stem densities since high stem population result in many tubers that compete for space within the ridge. In the presence of any process that leads to an accelerated rate of soil erosion on the surface of the ridge, the number of tubers exposed to direct sunlight and hence greening would increase. Since high densities may result in a high number of tubers, competition for space among the tubers within the ridge leads to increased chances of exposure to sunlight. According to reference [51] an increase in tuber volume that exceeds the soil volume surrounding the ridge led to tuber greening. Further, increased competition for nutrients and sunlight my result in shorter stems and hence, increased greening at high stem densities. References [9] and [52] suggested that longer stolons developing on short stems are most likely to expose the tuber to the soil surface leading to greening.

There is also room for researchers to investigate the influence of stem density on other important tuber quality determinants such as brown center, hollow heart, deformed tubers, nutrient content and some other processing attributes.

12. CONCLUSION

Our review showed that seed age is an important determinant of stem density. Young seed has few sprouts while old seed tubers have many weak sprouts that lead to a poor crop stand. A warm, moist soil that is loosely friable encourages rapid emergence of sprouts with the least resistance leading to a high stem density.

Stem density is directly related to the size of the seed tuber. The bigger the seed tubers the more the stems likely to develop per hill since large seed tubers have a greater assimilate reserve to support a dense population. Tuber yield and number per plant increase with an increase in stem density, while marketable yield declines. Increased inter-stem competition at high stem density results in a decrease in the average size of the harvested tuber.

Our review also revealed that the influence of variety and planting depth are yet to be fully understood. There is also need for further research in elucidating the response to stem populations of various tuber quality determinants such as nutrient content, specific gravity, dry matter content, hollow and brown heart.

We suggest that the most appropriate stem density would depend on the use of the crop, environment and variety. For seed producers whose main objective is to increase the multiplication rate of tubers, high stem densities per planting station have the potential of increasing plant populations resulting in many smaller tubers. In the production of certified seed, therefore, high stem densities increase the number of small sized tubers preferred by the seed market. For ware production, where size of the tuber matters, low stem densities promote a greater proportion of medium to oversized tubers required for French fries and other potato dishes. When a short growing period exists, one that is characterized by high rainfall, low temperatures, and less pest and disease incidence, use of multiple sprouted tubers will promote early emergence and crop establishment. When the production season is prolonged, establishment of low stem density populations allows for sufficient bulking without compromising the size of the tubers. Finally, stem density evaluations must be done across all the locally available potato cultivars to establish standard recommendations tailored made for each cultivar.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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