The Influence of Row Width and Seed Spacing on Uniformity of Plant Spatial Distributions

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Abstract

Crop performance and weed suppression increase with increasing crop spatial uniformity. We use spatial pattern simulations and field experiments to show the current state-of-the-art for spatial uniformity for different seeding technologies. We use Morisita's Index to quantify how changes in row width and evenness of spacing within rows influences two-dimensional spatial quality. The results can be used to define new requirements for improved seeding technologies to achieve higher benefits in sustainable crop production systems. In general it can be concluded that more even plant distributions are expected to result in a better crop plant performance.

Introduction

A central goal of technology in agriculture is to optimize crop growth by optimizing resource utilization. Current uneven ("clumped") crop spatial distributions of grains and row crops like maize and sugar beet can constrain crop performance because (i) resources like nutrients and water are not available to all crop plants in a optimal way, (ii) intra-specific competition within the crop populations starts very early in crop development and (iii) the ability to suppress weeds is limited by the crop spatial structure. The degree of spatial uniformity (evenness) is determined by the inter-row distance (row width) and the distribution of plants within the row. Plant density will affect the patterns if the row distance is not changed, since crop plants will be more crowded within the rows at higher densities.

Different seeding machines have different within-row spacing accuracies, determined primarily by their seed metering technologies. Other machine components as seed tubes and coulters also influence spacing accuracy [1, 2]. For grain drills with bulk metering, the frequency of plant spacing can be described by an exponential function. This means that the distribution does not have a mode near the mean spacing. Both grain drills with mechanical metering and those with pneumatic conveying typically show an exponential distribution of distances between adjacent individuals (CV = 1.0). When grain drills are used to sow oil seed rape (canola), the spacing accuracy if often worse (CV between 1.2 and 1.5). This is because of (i) a suboptimal design of the metering wheel for the low seeding rates (1 kg/ha rather than 100 kg/ha for which the machines are primary designed) and (ii) mechanical interference from fine powder from seed coat abrasion [3]. Improved seed metering systems are being developed by agricultural equipment manufacturers and prototypes are being tested [4].

Precision drilling gives much better seed distributions but is commonly used only for widely-spaced crops such as maize and beets. With closely-spaced crops like cereals and oil seed rape (canola), precision drilling is too expensive. For precision drills, variation in spacing occurs due to imperfect dosing (missing or double seeds) and seeds that do not emerge. The frequency distribution of spacing often has several modes, which are multiples of the mean spacing [2].

There have been several studies on the performance of sowing machinery and the resultant crop patterns of seedlings, but most of these have addressed only the evenness of within-row seed or plant spacing with one-dimensional analyses [5, 6]. The implicit assumption is that more even within-row spacing will result in a more uniform two-dimensional spatial pattern. There has been little two-dimensional spatial analysis of seeding patterns [7, 8].

There are three general categories of two-dimensional point patterns: (i) uniform (hyper-dispersed), (ii) random, and (iii) clumped (aggregated). It would be useful to describe the degree of two-dimensional spatial uniformity/aggregation of crop plants with a single measure on a continuous scale, which is independent of the sowing method used [9]. One well-known and accessible method for evaluating the spatial distribution of individual crop plants in agricultural experiments is Morisita’s Index of dispersion [10, 11, 12] which can be applied to x, y point-referenced data.

Morisita’s index of dispersion has been extensively used to evaluate the degree of dispersion/aggregation of spatial point patterns [10, 11]. Morisita’s index is based on random or regular quadrat counts, and is closely related to the simplest and oldest measures of spatial pattern, the variance-mean ratio, as well as other dispersion indices (see [12]). Because Morisita’s index can be calculated for different quadrat sizes, the scale of the analysis is not inherent, and it can be used to investigate pattern over a range of densities and scales.

Here we investigate and quantify the influence of both the row width as well as within-row seed spacing quality on the evenness (uniformity) of the 2-dimensional distribution of crop plants using field experiments and spatial computer simulations. The overall aim is to provide useful information for the choice of seeding machines and machine settings to improve spatial distribution for crop species such as wheat and maize. This information should also be useful in improving current seeding technology.

Materials and Methods

Field experiments

Field experiments were performed from 1998 - 2004 to investigate the effects of different crop spatial distributions (standard crop rows, random and highly uniform) on weed suppression and yield in weed-infested wheat. Seedlings were mapped by digitizing photographs, and these point patterns were used to measure lateral deviations within the row for use in the simulation model.

Computer generated patterns

A more theoretical approach is needed to quantify the influence of the two main parameters, row width and within-row seed spacing quality, on 2-dimensional spatial uniformity. The main parameters are (i) the rectangularity defined as row width divided by mean spacing within the row and (ii) the coefficient of variance (CV) of plant spacing between adjacent plants within the row. The use of the rectangularity makes the analyses independent of plant density. The set of x-y-referenced plant patterns were used as an input for software to calculate Morisita's Index, using the MATLAB software platform.

Pattern analysis

We generated 105 different 2-dimensional spatial point patterns by varying (i) rectangularity in the range of 0 to 7 in 0.5 increments and (ii) CV in the range of 0 to 1.5 in 0.25 increments to simulate common and other possible row sowing patterns, and then analyzed the resulting point patterns. We used Morisita’s Index of Dispersion (*I*) as a measure of spatial uniformity:

$$I = Q\frac{\sum_{i=1}^{Q} n_i(n_i-1)}{N(N-1)} \tag{1}$$

where

Q = the number of quadrates in the sampling area

n_i = the number of plants in quadrate i

N = the total number of plants in the sampling area.

I ranges from 0 (completely uniform), over 1 (random) to Q (the most clumped arrangement, when all points occur in one quadrat, and I equals the number of quadrats). Morisita’s Index is most informative when the quadrats are small relative to the scale of pattern to be described. The index values were used to generate contour maps with SURFER computer software.

Results and Discussion

The Morisita index *I* varies greatly as a function of the CV and the rectangularity (Fig. 1). The lowest spatial uniformity occurs when the CV and the rectangularity are at their maximum (upper right corner). The highest spatial uniformity is achieved by setting the rectangularity to 1 together with a CV of or close to 0, which generates a "grid-like" pattern.

The isocline of *I*=1.0 indicates all patterns whose degree of uniformity is equal to that of a "broadcast pattern", i.e. a 2-dimensional random pattern (*I*=1). A broadcast pattern occurs when the distribution within the row is random (CV=1) and a row width or a rectangularity is 0. The uniformity of the pattern decreases as the row distance increases from 0. This means that if crops are sown in rows, "better than random" uniformity can only be achieved by improving the evenness of spacing within the rows, such that CV<1. The results also indicate that a degree of uniformity equal to that of a 2-dimenional random pattern can be achieved up to a rectangularity value of 5 if the plant spacing within the row is almost perfect (CV=0). Ideally the isocline of *I*=1 should cross the y-axis at a value of CV=1. Due to the complex simulation structure of the pattern generation and the data analysis the results obviously are not fully backing up precisely the theoretical assumptions.

Four current state-of-the-art crop sowing patterns are noted on Fig. 1. Grain crops typically show random plant spacing (CV=1) and a row width ratio of almost 6 (row width 12 cm and 400 plants/m^2) and spatial uniformity of *I*=2.25. The results show that small improvements in the within-row distribution or a small reduction in row width do not give major improvements in spatial uniformity. With bulk seeding technology (CV=1) the row width should go down to 4 cm (rectangularity=1) to achieve a significant change (*I*=1.00).

Canola sowing patterns have a random plant spacing (CV=1) and a row width ratio of around 1.4 (row width 12 cm and 100 plants/m^2). Current canola seeding results in a degree of uniformity somewhat worse than that of a random spatial pattern (*I*=1.05). The most promising way to improve the spatial pattern in Canola would be to use precision seeding which will give a more even plant spacing (CV=0.5) and a better spatial distribution (*I*=0.6).

For maize a multi mode Gaussian within-row distribution is typical (CV=0.5) with a rectangularity of around 5.5 (row width 75 cm and 10 plants/m^2). The more even plant spacing occurs because precision drilling is more common for maize than bulk seeding (*I*=1.5). Due to the better plant spacing evenness, the spatial pattern is better than that of grain crops but still much worse than a random distribution. Improved spatial uniformity can be achieved in maize by decreasing row width. For example a 32 cm row width (rectangularity=1) would improve the spatial pattern greatly (*I*=0.6).

Sugar beet show also a multi mode Gaussian distribution similar to that of maize (CV=0.5) but a rectangularity of around 2.5 (row width 50 cm and 10 plants/m^2). The more even plant spacing is due to precision drilling and results in more even spatial patterns (*I*=0.8). Again, since precision drilling is already standard, improvements in uniformity can be best achieved by reducing row width. Sugar beet seeding at 32 cm instead of 50 cm row width (row width ratio=1) would result in a slightly better spatial pattern *(I*=0.6).

The described geometric pattern analysis gives an impression about how to improve conditions for crop growth in relation to intra-specific competition and resource utilization. However, the effects of uneven stands vary depending on the species, the genotypes and according to the environmental conditions [13]. In general it can be expected that more even plant distributions will result in a better crop plant performance.

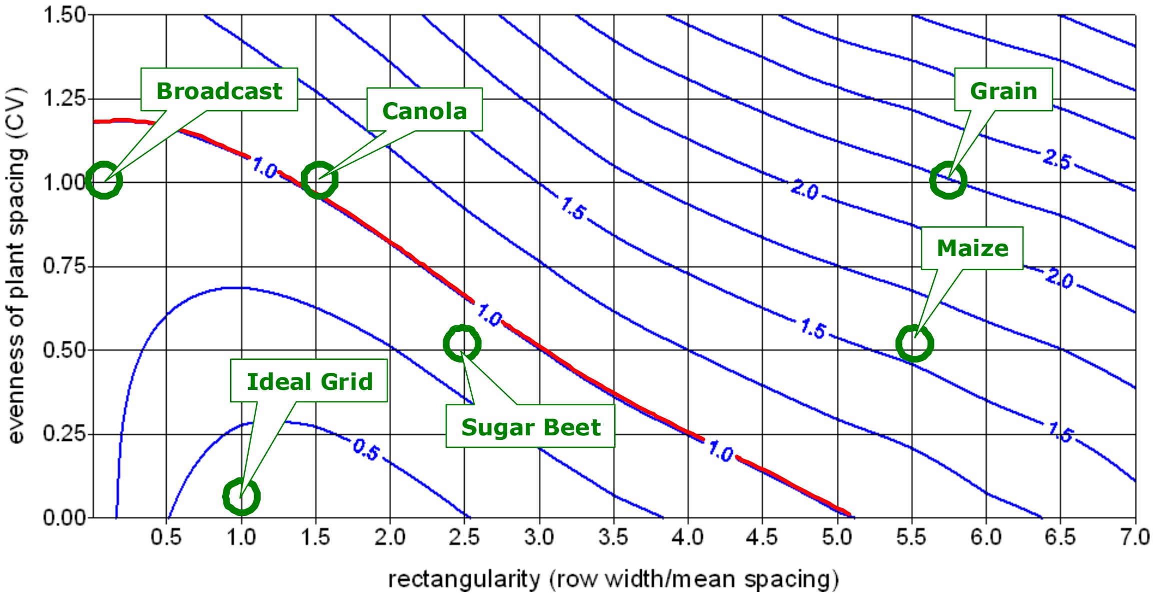

Fig. 1: State-of-the-art of seeding technology for crop establishment in relation to spatial uniformity. Contour lines reflect the spatial uniformity expressed by the Morisita index. Index values range from 0 (completely uniform) to 1 (random) and more than 1 (clumped or aggregated patterns)

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