Scientific bases of principles estimating a state of the vegetation cover in steppe agrocenoses using innovative methods of smart agriculture

Yu A Gulyanov

Institute of Steppe of the Ural Branch of the Russian Academy of Sciences, Orenburg, Russia

E-mail: orensteppe@mail.ru

Abstract. The study's main target is to actualize notions about spatial heterogeneity of steppe agrocenoses in conditions of the current climatic and anthropogenic changes, scientific grounds of instrumental methods estimating a state of the vegetation cover, and to identify optimal phytometric parameters of high productive agrocenoses of crops. Industrial winter wheat plantings and demonstrative seeds of spring wheat, sunflower, barley, maize, soya, winter rye, and winter wheat on the chernozem in Orenburgskaya oblast were objects of the study. High technological agrocenoses of spring wheat on chernozem in Samarskaya oblast and winter wheat on dark-chestnut soils in Saratovskaya and Volgogradskaya oblasts were used in the research. Normalized Difference Vegetation Index (NDVI) of crops was measured by a portable device - Green Seeker Handheld Crop Sensor, Model HCS – 100. The assimilating area of plants was estimated by the gravimetric method. Generally accepted practices of the statistical analysis were used in the processing of digital material. As a result of the study, spatial differences in the vegetation cover state of field agrocenoses were detailed by its instrumental examination. It was ascertained that the vegetation cover's heterogeneity began to show at the start of vegetation and did not level itself. In the following stages, we could see that proved reasonability to examine plantings instrumentally starting from the early stages when the technical correction was possible. Detection of optimal phytometric parameters of agrocenoses of different types of crops in regions of the steppe zone in the European part of Russia by NDVI evaluation on stages of plant development in zonal climatic and soil conditions under high levels of agrotechnologies was offered to estimate a state of the current plantings and to make technological solutions correcting the course of vegetation.

1. Introduction

In conditions of the current climatic and anthropological changes, an increase of photosynthetic productivity of seeds by optimization of the environmental factors will promote soil degradation occurring everywhere that leads to intra-field heterogeneity of the vegetation cover (figure 1) and formation of low and heterogeneous harvests, the complete realization of the genetic resources of crops.

That support of phytometric parameters of agrocenoses on the optimal level corresponding to the high realization of harvest potential recommended to varieties planting having zonal, species, and even kinds specifics is possible only in their constant monitoring during vegetation. Modern agrarians have such an opportunity due to the introduction of innovative methods of smart land use. For example, high-resolution satellite imagery and ground portable scanning devices can be used to identify the
Normalized Difference vegetation Index (NDVI) tightly correlating with the area of assimilating surface of plants [1, 2].

Figure 1. Heterogeneity of the vegetation cover in agrocnoses with winter wheat (May 2019) and spring wheat (June 2019) on common chernozem in the steppe soil-climatic zone of Samarskaya oblast.

Technical equipment of the modern branches of plant growing, especially in large farms (holding companies), promotes to "correct" the basic structural parameters of agrocnoses during the vegetation and level heterogeneity of conditions of plant growth, for example, using differentiated mineral additional fertilizing in the system of precision agriculture [3].

Following it, the scientific basis of innovative methods estimating the vegetation cover state in field agrocnoses, especially in grain-production regions of the RF steppe zone, has a high actuality. Their results represent practical interest.

The principal target of the study is to actualize notions on spatial heterogeneity in the steppe agrocnoses in conditions of the current climatic and anthropologic changes, explain scientifically instrumental methods estimating a state of the vegetation cover, and identify optimal phytometric parameters of high productive agrocnoses of crops for separate regions of European Russia.

The following tasks were formulated to realize the set goals:

- To actualize notion on spatial differences of a state of the vegetation cover in one-specific agrocnoses of crops, to observe the variability of NDVI in winter wheat's seeds within test sites of a field and vegetation phases;
- To identify links between phytometric parameters of the winter wheat agrocenosis during maximal photosynthetic productivity (ear formation-blooming) and similar parameters in the first stages (spring tillering) and generalize reasonability of the instrumental inspection (assessment) of a state of the vegetation cover to make correcting technological decisions;
- To reveal optimal phytometric parameters and NDVI values corresponding to them for high productive agrocnoses of crops in separate regions of the Russian steppe zone;
- To expose species and zonal specifics of identification of phytometric parameters of seeds by NDVI, to generalize given results and formulate a conclusion.

2. Materials and Methods

Industrial seeds of winter wheat and demonstrating spring wheat seeds, barley, sunflower, maize, soya (the Saraktashskiy district), winter rye, winter wheat (the Orenburgskiy district) on common chernozem in Orenburgskaya oblast were the objects of the study. High productive agrocnoses of spring wheat (the Neftegorskiy district) on southern chernozem in Samarskaya oblast and winter
wheat on dark-chestnut soils in Saratovskaya oblast (the Marxovskiy district) and Volgogradskaya oblast (the Olkhovskiy district) were researched (figure 2).

![Figure 2. High-technology demonstrative seeds of sunflower (2019) and winter wheat (2020) on common chernozem in the central soil-climatic zone of Orenburgskaya oblast.](image)

The Normalized Difference Vegetation Index (NDVI) was measured by a portable device Green Seeker Handheld Crop Sensor, Model HCS - 100 (figure 3). The algorithm of its work and methodological instruction of its use was described in our previous papers [4].

![Figure 3. Realization of the innovative method estimating a state of the cover vegetation of winter rye agrocenosis on common chernozem in the central soil-climatic zone of Orenburgskaya oblast, 2020.](image)

The area of the assimilating surface of plants was measured by the gravimetric method. Generally accepted practices of the statistical analysis were used in the processing of digital material.

3. Results and Discussion

Notions on spatial differences in the state of the vegetation cover of one-type agrocenoses of crops are actualized in the course of the study [5,6]. The visually perceptible "mixed character" in the plant stand, the power of development of leaf apparatus, a height of a plant, and intensity of their color were empirically corroborated and detailed using an instrumental examination of seeds. Variability of NDVI of crops was revealed between separate fields, inside testing sites of these areas, taking into
account plant vegetation stages. Thus, a diapason of the variability of the NDVI and its dynamics according to vegetation stages was identified in 45 testing sites of fields with winter wheat on common chernozem in the Orenburg Cis-Urals region (figure 4).

![Diagram of NDVI variability in different sites of a winter wheat agrocenosis on common chernozem in the Orenburg Cis-Urals region, 2019-2020.](image)

**Figure 4.** Variability of the normalized difference vegetation index (NDVI) in different sites of a winter wheat agrocenosis on common chernozem in the Orenburg Cis-Urals region, 2019-2020.

The least variability of NDVI, an average of 2.4-2.5%, was noticed in the periods of maximal development of plants’ assimilation apparatus corresponding to stages from shooting to ear formation and blooming. At the beginning of vegetation, in autumn and spring tillering stages, the NDVI variation coefficient was 3.9-4.0%. The most dynamics were seen in the second part of vegetation under grain formation and ripening. It reached 6.5-9.3% for this period. In absolute terms, the most considerable NDVI value was registered in site 4; a bit lower values were in areas 1 and 2, and the least – in place 3. According to stages of plant development, the difference between average NDVI values of analyzed sites was 0.15-0.16 units at the beginning of vegetation, 0.17-0.18 units in stages of shooting, tillering, and blooming, and 0.12-0.06 units – in the stage of grain formation and ripening. Absolute average NDVI values according to the mentioned stages of plant development were equal for three years of the study 0.69-0.71, 0.72-0.76 and 0.65-0.26 units, respectively. The highest NDVI indicators reached 0.75-0.79 units in separate sites of the field. They were noticed in the maximal phytometric parameters and maximal photosynthetic productivity of plants in shooting ear formation-blooming stages.

It was ascertained that heterogeneity of the vegetation cover outlined at the beginning of vegetation in testing sites of a field did not level itself and was seen in each following stage. Regression analysis of experimental data received from 58 testing sites showed a close relation (ϕ = 0.81) of NDVI values in winter wheat agrocenoses at the beginning of vegetation (spring tillering) and in the period of maximal photosynthetic productivity (ear formation-blooming).

The regression equation describes a relation = 0.415x + 0.483, where x - NDVI in the stage of spring tillering, y – NDVI in the ear stage formation-blooming. The coefficient of determination (r^2 = 0.659) confirms a dependence of the mentioned indicators in 65.9% cases or NDVI dynamics in the stage of spring tillering at 65.9% determines a variation of NDVI in the stage of ear formation-blooming (figure 5).
The data given above show the reasonability of instrumental examination of agrocenoses of crops for NDVI correspondence to its optimal (normalized) values beginning from the early stages when the technical correction is still possible.

In the result of scale studies with various kinds of traditional crops, conducted in four oblasts of the steppe zone in European Russia (Orenburgskaya, Samarskaya, Saratovskaya, Volgogradskaya oblasts), we identified optimal phytometric parameters and NDVI values corresponded to them that are typical for high productive agrocenoses adapted to the current climatic and anthropogenic changes. In the result of the correlated analysis of experimental data, a strong relation of the mentioned parameters was confirmed \((r = 0.78-0.97)\). We have already noticed this relation in agrocenoses of winter wheat in the Orenburg Cis-Urals region [6] and other areas of the Russian steppe zones [7].

As the existing studies show, in conditions of the central Orenburzhie (the Orenburgskiy, Saraktashskiy districts), an optimal area of the assimilating surface of spring durum wheat in the tillering stage is 11.3-11.4 thousand \(\text{m}^2/\text{ha}\), and in the stages of ear formation-blooming – 16.6-16.7 thousand \(\text{m}^2/\text{ha}\) and 18.1-18.2 thousand \(\text{m}^2/\text{ha}\), respectively (table 1).

Mentioned phytometric parameters of wheat agrocenoses correlate NDVI 0.57 units in the tillering stage and 0.63-0.61 units in the stages of shooting and ear formation-blooming. In agrocenoses of barley, the higher values are seen – NDVI 0.64 (tillering) – 0.72-0.70 units (shooting and ear formation-blooming), and the area of the assimilating surface corresponded to them – 12.6-12.7 thousand \(\text{m}^2/\text{ha}\) – 20.6-20.7 thousand \(\text{m}^2/\text{ha}\). Later, in the order of increasing of the mentioned values (Table 1), agrocenoses of sunflower are placed. It has the optimal area of leaves, 24.0 thousand \(\text{m}^2/\text{ha}\) in the stage of head blooming and NDVI 0.83 units. Relative values of the analyzed parameters characterize maize and winter wheat agrocenoses in the aboveground biomass formation period – NDVI 0.78-0.79 units and the assimilating surface area 25.6-25.8 thousand \(\text{m}^2/\text{ha}\). The highest phytometric characteristics of seeds are noticed in winter rye and soya agrocenoses. They have the maximal area of assimilating surface - 29.5-35.7 thousand \(\text{m}^2/\text{ha}\), NDVI corresponds to it - 0.85 units. We should underline that we did not find a direct proportional dependence between the area of assimilating surface and corresponding NDVI value in the whole in groups of represented crops. It confirms individual physiological peculiarities of various kinds and indicates the necessity "private" approach to analyzing results of seeds monitoring. It was ascertained that the highest values of the area of the assimilating surface corresponded to each 0.01 NDVI units were seen in soya agrocenoses at the beginning of the blooming stage (432.4 \(\text{m}^2/\text{ha}\)). Indicators exceeding 300.0 \(\text{m}^2/\text{ha}\) are typical for winter rye agrocenoses (346.8 \(\text{m}^2/\text{ha}\)) and winter wheat (325.6 \(\text{m}^2/\text{ha}\)) in the period of ear formation-blooming, and maize (329.0 \(\text{m}^2/\text{ha}\)) - in the stage of panicle blooming. In spring wheat, barley, and sunflower agrocenoses, the mentioned parameters' values reach 300.0 \(\text{m}^2/\text{ha}\) in the ear formation-blooming stage (spring wheat, barley) and head blooming (sunflower).

**Figure 5.** A link of NDVI values in a winter wheat agrocenosis in phases of spring tillering and ear formation-blooming, average values for 2018-2020.
Table 1. Phytometric parameters of high-technological agrocenosis of particular types of crops in the RF steppe regions, average values for 2018-2020.

| Crop, region | Stage of development | Vegetation Index (NDVI), units | Leaf area (LA), m²/ha | Relation of LA to NDVI, m²/ha at 0.01 unit of NDVI |
|--------------|----------------------|-------------------------------|-----------------------|-----------------------------------------------|
| Spring wheat, Orenburgskaya oblast | tillering | 0.57 | 11386 | 199.8 |
| | shooting | 0.63 | 16615 | 263.7 |
| | ear formation-blooming | 0.61 | 18173 | 297.9 |
| Barley, | tillering | 0.64 | 12693 | 198.3 |
| Orenburgskaya oblast | shooting | 0.72 | 17319 | 240.5 |
| | ear formation-blooming | 0.70 | 20666 | 295.2 |
| Sunflower, 4-5 pairs of regular leaves | head formation | 0.80 | 18616 | 232.7 |
| Orenburgskaya oblast | blooming | 0.83 | 23948 | 288.5 |
| Maize, | shooting | 0.63 | 15221 | 241.6 |
| Orenburgskaya oblast | 9 leaves | 0.76 | 21313 | 280.4 |
| | blooming | 0.78 | 25663 | 329.0 |
| | branching | 0.69 | 18602 | 269.6 |
| Orenburgskaya oblast | the start of blooming | 0.78 | 33730 | 432.4 |
| | pod formation | 0.85 | 35612 | 418.9 |
| Winter rye, | spring tillering | 0.80 | 19713 | 246.4 |
| Orenburgskaya oblast | shooting | 0.87 | 26554 | 305.2 |
| | ear formation-blooming | 0.85 | 29477 | 346.8 |
| Winter wheat, | spring tillering | 0.76 | 15916 | 209.4 |
| Orenburgskaya oblast | shooting | 0.78 | 20637 | 264.6 |
| | ear formation-blooming | 0.79 | 25772 | 325.6 |
| Spring wheat, | tillering | 0.59 | 12335 | 209.1 |
| Samarskaya oblast | shooting | 0.65 | 18769 | 288.8 |
| | ear formation-blooming | 0.65 | 21110 | 324.8 |
| Winter wheat, | tillering | 0.80 | 15332 | 191.7 |
| Saratovskaya oblast | shooting | 0.82 | 20216 | 246.5 |
| | ear formation-blooming | 0.83 | 26773 | 322.6 |
| Winter wheat, Volgogradskaya oblast | tillering | 0.81 | 16718 | 211.6 |
| | shooting | 0.83 | 21448 | 258.4 |
| | tillering-blooming | 0.84 | 28815 | 343.0 |

Notably, in zonal conditions of Samarskaya oblast, spring wheat forms a more developed photosynthetic apparatus that is noticed during the whole vegetation. Thus, according to the assimilating surface areas, agrocenoses in Samarskaya oblast exceeds similar seeds in Orenburgskaya oblast at 949.8-2154.0-2937.0 thousand m²/ha in stages of tillering-shooting-ear formation-blooming, respectively. In the mentioned dates of the forming, seeds are characterized by higher NDVI and the area of the assimilating surface corresponding to every 0.01 units of NDVI (Table 1). Even more expressed, similar trends are registered in winter wheat agrocenoses in zonal conditions of Saratovskaya and Volgogradskaya oblasts. Under the total orientation of NDVI and phytometric parameters’ change during the vegetation, in the mentioned regions, higher NDVI values are notice corresponded to the similar areas of the assimilating surface of plants. The data confirms zonal peculiarities of a photosynthetic apparatus formation in one-kind agrocenoses of crops. It should be taken into account, along with species specificity, in identifying phytometric parameters using NDVI in activities estimating a state of the vegetation cover.
4. Conclusion
In the current soil-exhausting approaches in agriculture and not always high agro technologies, there is the possibility of inside-field heterogeneity of the vegetation cover. It connects with different conditions of separate plant growing in agrocenosis; it is expressed in various degrees of their development and often represents the dynamics of phytometric parameters leading to "mixed character" of productivity and quality. Detection of the normalized difference vegetation index (NDVI) of seeds tightly correlated with the assimilating surface area should be used to efficiently identify the inside-field heterogeneity of the vegetation cover and the following safe ecological leveling of conditions of plant growth by agrotechnical means. Identification of optimal (normative) phytometric parameters of agroecoses of various kinds of crops in the regions of the steppe zone in European Russia by means NDVI according to stages of platforming in zonal climatic and soil conditions under high levels of agro technologies can serve as a basis estimating a state of the current seeds and making correcting technological decisions in the course of vegetation. For traditional crops of Orenburgskaya oblast, optimal (normative) NDVI values in the early stages of vegetation that are "responsible" for the formation of the future harvest are: 0.57 (tillering) – for spring wheat, 0.64 (tillering) – for barley 0.66 (4-5 pairs of real leaves) – for sunflower, 0.63 (shooting) – for maize, 0.76 (spring tillering) – for winter wheat, 0.69 (branching) – for soya, and 0.80 (spring tillering) – for winter rye. In zonal conditions of Samarskaya oblast, in spring wheat agroecoses directed to high realization of the genetic potential of kinds recommended for cultivation, NDVI should be no less than 0.59-0.60 units in the tillering stage. In winter wheat agroecoses – the principal grain culture in Saratovskaya and Volgogradskaya oblasts, the optimal indicators of the mentioned parameter correspond to 0.89-0.81 units in the stage of spring tillering.

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