Nilakantha's work For instance, Pingree in his review article on Indian astronomy presents the mean rates of motion of Mercury and Venus given in *Tantrasangraha* as the rates of motion of their *sighroccas* (Pingree, D , History of Mathematical Astronomy in India, in *Dictionary of Scientific Biography*, New York, 1978, vol XV, p 622)

9 Ref 7, pp 44–46.

10 Ref 7, p 139

11 See for example (a) *A History of Astronomy from Thales to Kepler*, Dreyer, J L. E , Dover, New York, 1953, (b) *Mathematical Astronomy in Copernicus' De Revolutionibus*, Swerdlow, N M and Neugebauer, O., Springer, New York, 1984, 2 vols.

12 See for example *The Almagest* by Ptolemy, Tr by Taliaferro R. C., in *Great Books of the Western World* (ed. Hutchins, R. M.), Chicago, vol. 16, 1952. For the exterior planets, the ancient Indian planetary model and the model described by Ptolemy are very similar except that, while the Indian astronomers use a variable radius epicycle, Ptolemy introduces the notion of an equant. Ptolemy adopts the same model for Venus also, and presents a slightly different model for Mercury. In both cases the equation of centre is applied to the mean Sun While the ancient Indian astronomers successfully used the notion of the *sighrocca* to arrive at a satisfactory theory of the latitudes of the interior planets, the Ptolemaic model is totally off the mark when it comes to the question of latitudes of these planets This difficulty with the computation of latitudes persisted till around the time of Kepler

13 Kern, B (ed), *Aryabhatiyam* with *Vyakhya* of Paramesvara, Leyden, 1885, pp 68–69

14. Kuppanna Sastri, T. S. (ed), *Mahabhaskariyam* with Govindasvamin's *Vyakhya* and *Siddhantadipika* of Paramesvara, Madras Govt Oriental Series, No 130, 1957, pp 233–238

15 Sarma, K V. (ed), *Grahasphutanayane Vikshepavasana* of Nilakantha Somasutvan in *Ganitayuktayah*, Hoshiarpur, 1979, pp. 61–64.

16 Sambasiva Sastri, K. (ed), *Aryabhatiyam* with the *Bhashya* of Nilakantha Somasutvan *Kalakriyapada*, Trivandrum Sanskrit Series, No 110, 1931, p. 53.

17. Sarma, K. V. (editor and translator) *Siddhantadarpana*, Hoshiarpur, 1976, pp 18–19

18 This reflects the feature of Indian planetary models, that the *manda* correction or the equation of centre is calculated from a variable radius epicycle model See for instance *Mahabhaskariya* of Bhaskaracharya, I., ed. and translated by Shukla, K. S., Lucknow, 1960, pp. 136–146.

19. Ref 15, p. 63.

20. Ref. 6, p. 9.

21. Sarma, K. V. (ed) *Sphutanirnayatantra* of Acyuta Pisarati, Hoshiarpur, 1974; *Rasigolasphutaniti* of Acyuta Pisarati, ed. and translated by Sarma, K. V , Hoshiarpur, 1977.

22 Ref 6, p 6

23 The well known Orissa astronomer of last century, Chandrasekhara Samanta, who was trained solely in traditional Indian astronomy, seems to have also discussed a model of planetary motion where the five planets go around the Sun, in his work *Siddhantadarpana*. (*Siddhantadarpana* of Mahamahopadhyaya Samanta Sri Chandrasekhara Simha, Calcutta 1897, V. 36. See also the review by W E.P. in *Nature*, 1532, 59, 437, 1899). We are grateful to Dr P. Nayak for bringing this important fact to our attention

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N. I. Vavilov, Martyr to genetic truth

James F. Crow

Fifty years ago, on January 26, 1943, Nikolai Ivanovitch Vavilov, near starvation, died in a Soviet prison hospital. He was 55, at what should have been the peak of his career. On this 50th anniversary of his death, the most shortsighted of the many genetics tragedies in the Stalin-Lysenko era, it is fitting that he be memorialized in this journal. This comes at a time of dissolution of the USSR, with its enormous problems which we hope are temporary, and its augury of a better political and scientific tomorrow.

Genetics was fated to be caught up in the two most devastating European dictatorships of the century. Hitler's notorious racist polices deprived Germany and the world of some of our greatest minds and clouded human genetics for decades. Stalin, by supporting Lysenko's bizarre Lamarckism, set Soviet genetics a generation behind.

I first heard the Vavilov story from H. J. Muller while visiting him at Amherst College during World War II. He had spent four years in Russia, from 1933 to 1937, at Vavilov's invitation. He had gone there with high hopes for an expanded, well supported genetic research programme and had come back thoroughly discouraged. Geneticists had been disappearing – 18 of Vavilov's staff members were arrested between 1934 and 1940 – and the programme was devastated. At the time of our conversations Muller knew of Vavilov's arrest, but not whether he was still alive. In those years Russia was our ally and Muller was unwilling to say things that would undermine the US-USSR cooperation. Furthermore, he was reluctant to speak out against the state of genetics in the USSR for fear of further jeopardizing his friends and students there; but he was happy to talk privately. Later, after the war, when he decided that his silence was not helping, he became an outspoken opponent of the Lysenko fiasco.

Vavilov was a man of prodigious energy, personal charm, contagious enthusiasm, retentive memory, encyclo-

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pedic knowledge and linguistic talent. He spoke all the major European languages, and on his trips he managed to learn enough words to get along in one country after another as he travelled in search of wild relatives of cultivars. Muller spoke of Vavilov's great physical energy, his sleeping only 4–5 hours per night and his writing articles while travelling. An early favourite of Lenin, he headed the All-Union Institute of Plant Breeding. He had written more than 350 articles and books. He had won awards throughout the world. He was Vice-President of the Sixth International Congress of Genetics and had been elected President of the Seventh. How could such a man be challenged?

His downfall came from the ambitious Trofim Lysenko, who managed to win favour with Stalin. Lysenko had attracted attention with the technique of vernalization, by which cold treatment of seeds altered development in a way said to hasten maturity and increase yields. Vavilov actually promoted Lysenko by praising these results at the Sixth International Genetics Congress in 1932. By this time Vavilov was being criticized for failing to produce the hoped-for increases in agricultural productivity. His method of collecting wild relatives of cultivars from around the world would yield only slow (but certain) improvement. Lysenko, with his naive Lamarckian views, promised quick results. The debates were vigorous and even Muller got into the act. I have always liked something he said in one of the debates. He asked what hope there could be for a proletarian revolution when the poor had suffered generations of bad environments, which on a Lamarckian interpretation would have ruined their genetic potential. The answer is not recorded.

Lysenko came from a peasant background, which gave him prestige. (In contrast, Vavilov came from a wealthy family.) Lysenko's Lamarckian ideas fitted the political climate. Most important, he had Stalin's support. A major reason for Lysenko's ascent was his promise of quick crop improvement compared to Vavilov's slow process of systematic collection of wild varieties, hybridization, testing, and selection. The public criticisms brought against Vavilov also included such things as giving too much attention to 'fascistic' foreign science, wasting government money on useless collecting trips, and holding idealist Mendelian theories. Vavilov was removed from his high post in the Central Executive Committee in 1935. His successor was A. I. Muralov, who was arrested in July, 1937; *his* successor was G. K. Meister, who was arrested in February, 1938. Not a very safe line of work. Then Lysenko took over. I have mentioned earlier (Crow 1992) that Vavilov was prevented from attending the Seventh International Congress, held in Edinburgh in 1939, despite being its President. Vavilov never heard the words of high praise given by F. A. E. Crew and others at the Congress.

A photograph of N. I. Vavilov from the 1932 International Genetics. Reprinted from Mangelsdorf (1953).

Vavilov refused to follow the politically expedient path of supporting Lysenko's theories. He clearly knew that trouble lay ahead, but he did not retreat from his scientific views. He advised Muller to leave, which Muller did by working in a blood bank in Spain. He thought that supporting the Spanish loyalists would be the best way not to be branded a bourgeois reactionary deserter; it didn't help. Muller said that the last conversation between the two of them, in 1937, was held *outside* Vavilov's apartment, lest they be overheard. Muller also carried a secret message from Vavilov to N. Timofeeff-Ressovsky warning him to stay away from Russia. Timofeeff-Ressovsky was a Russian geneticist, then working in Germany and wanting to leave for his homeland; but return would have meant certain imprisonent.

Vavilov was arrested on August 6, 1940, while on a collecting trip in the Ukraine. He was tried and sentenced to be shot for, among other things, belonging to a rightist organization, spying for England, sabotaging agriculture and maintaining links with émigrés. After a short time in a Moscow prison he was moved 450 miles southeast to Saratov, where 20 years earlier he had been Professor at Saratov University and first attained prominence. The British Royal Society elected him to membership in the hope that this might save his life. His supporters, especially his mentor Pryanishnikov, made a strong plea for clemency and Vavilov also had help from his physicist brother Sergei, later to be president of the Soviet Academy of Sciences. The death sentence was rescinded in June, 1942, but Vavilov remained imprisoned until his death in 1943. His name was removed from the list of members of the Soviet Academy of Sciences in 1945.

Many other geneticists were also victims at about the time of Vavilov's arrest, including his famous associate G. D. Karpechenko. Karpechenko had hybridized radish and cabbage to produce the enormously luxuriant allopolyploid *Raphanobrassica*, a textbook example of extreme heterosis. An earlier 'liquidation' was Solomon Levit, the leading Soviet human geneticist.

According to Popovsky (1984, p. 181), Vavilov, while confined to a crowded prison cell, 'brought a measure of discipline into things. He tried to cheer up his companions. To take their minds off grim reality he arranged a series of lectures on history, biology and the timber industry. Each of them delivered a lecture in turn. They had to speak in a very low voice because if the guard heard them he would order them to talk only in a whisper.' It is reminiscent of Timofeeff-Ressovsky's lectures to fellow prisoners a few years later after he had returned to Russia and had been arrested as Vavilov warned. It is vividly described by Solzhenitsyn in *The Gulag Archipelago*.

Vavilov was born in Moscow on November 25, 1887, and graduated from high school in 1906. He then became a student at the Moscow Agricultural Institute and graduated in 1911, winn-

ing a prize for his thesis on garden slugs. The greatest scientific influence on his career, he said, came from his study with William Bateson in England. His first work, on his return to Russia, was on disease resistance in plants. He was particularly interested in identifying resistant varieties, in some cases finding that a single gene was responsible. One of his discoveries was *Triticum timopheevii*, a wheat variety resistant to several diseases, which has been widely used as a source of resistant germ plasm. He also had the idea that if a parasitic fungus has a wide range of hosts, it is less likely that resistant varieties will be found in any of the host varieties than if it were host-specific.

Vavilov's interest in wild relatives of cultivated species led to ambitious expeditions throughout the world. By 1940 more than 250,000 plants had been collected. These were not just museum specimens, but seeds and live plants. They were studied taxonomically, cytologically and genetically in more than 400 experiment stations throughout the Soviet Union. The idea was to provide breeders with the full genetic potential of the species and the means for creating new and better varieties. He had a program of testing each variety in many habitats to find those best suited to each particular environment. He was especially interested in finding strains that would mature and produce high yields in the short growing season that plagues much of the Soviet Union. In short, he carried out on an unprecedented scale the kind of plant breeding program that has since been practiced in agricultural experiment stations throughout the world. The All-Union Institute of Plant Breeding, of which he was the head, at one time had some 20,000 workers.

Vavilov noted that closely related species had similar variations. In those pre-molecular days, similarity of variants was one of the best indicators of genetic relationship. His law of 'homologous variation' held that the more similar species are, the more similar are their patterns of variation. This way of classification became very popular, and he was sometimes able to predict that a particular variant would be found. This predictive idea was even compared to Mendeleev's periodic table. The theory was naturally controversial, and some took it as evidence against Darwinism. L. S. Berg, for example, regarded similar variations in related species as evidence for a predetermined evolution, 'nomogenesis' as he called it. Later, Vavilov relied on additional techniques, such as cytogenetics; but he always regarded homologous variation as an important measure of genetic relationship.

The work of greatest lasting influence was his search for the origins of domestic plants. He formulated the hypothesis that locales in which there is the largest amount of genetic variability are the ones from which new varieties, the future cultivars, arose. Vavilov found some parts of the world to be particularly rich in varieties, and he regarded these as the centers from which the crop plants were descended. These areas also were often the sites of origin of civilizations.

In retrospect, the hypothesis has not stood up very well. Cultivated varieties have not regularly come from the areas of greatest diversity. But, such centers have turned out to be of great utility in the search for sources of new germ plasm for plant improvement. Vavilov's foresight shines through in these times of concern for preservation of genetic diversity. Ironically, the work that was tarred as idealistic has turned out to be of great practicality, far more so than Lysenko's fanciful schemes.

Lysenko was an unmitigated disaster, not only for Soviet genetics but for agriculture as well. He fostered one hare-brained scheme after another, each being put into practice on a wide scale. Controlled experiments and the efficient experimental designs introduced by R. A. Fisher were no part of his program. His lack of controlled pollination led to varieties losing their identity. Hybrid corn, derived from puny inbred parents, was derided as fatuous Morgan-Mendelism. Vavilov's efforts to introduce American corn-breeding methods were totally rejected. The wonder is that agricultural production did not fall still lower.

Vavilov was a strong believer in the importance of selection, both for evolution and as a tool for the plant breeder. Finding diverse types, hybridizing them, and especially selecting among the recombinants, gave the best hope for producing better plants. And, of course, he was right But the slow and certain program he was advocating could not compete in the political arena with those who promised instant gratification. Here lies a lesson for all science.

Vavilov's foresight is preserved in the Vavilov Institute in St. Petersburg, now one of the world's largest and most varied repositories of plant germ plasm. It is located in one of the central squares and Vavilov now holds a position of high respect, one more example of the custom – not confined to the Soviet Union – of killing people before honoring them.

Throughout his tragically truncated life, Vavilov had both scientific and utilitarian goals. He thought of his wide-ranging geographical studies – more than 40 trips outside the Soviet Union and many more within – as adding to our understanding of evolution by natural selection. But it was also a way of improving plants and adapting them to new areas. He had the resources to carry out such a program, and in time would surely have produced the results he foresaw. He believed that the Soviet Union gave scientists a better opportunity to advance knowledge and serve mankind than any other country, and for this reason overlooked the crudities and cruelties of the regime. Alas, the crudities and cruelties soon predominated. Vavilov's favorite saying, particularly poignant as it turned out, was: 'Life is short; hurry.'

1 Information not identified as to source has come mainly from the book by Popovsky and the articles by Adams and Mangelsdorf.
2 Adams, M B, 1978 Vavilov, Nikolay Ivanovich. *Dictionary of Scientific Biography*, **15**: 505–513. Charles Scribner's Sons, New York.
3. Crow, J F, 1992 Sixty years ago: the 1932 International Congress of Genetics Genetics, **131**: 761–768
4. Mangelsdorf, P. C., 1953 Nikolai Ivanovich Vavilov, 1887–1942. Genetics, **38**: 1–4.
5. Popovsky, M. A, *The Vavilov Affiar.*, 1984, Archon Books, Hamden, Conn

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